Grid integration of variable renewable energy

Voltage control with PV in distribution grids

Albrecht Tiedemann (RENAC)

renac
renewables academy

www.renac.de

About Albrecht Tiedemann

renac
renewables academy

- Since 2009: Renewables Academy (RENAC) AG; Head of grid integration / energy policy and wind energy division; Lecturer for training programs on grid integration of renewable energy and wind energy, capacity building programs and the E-learning platform RENAC-Online

- 2003 – 2009: German Energy Agency; Project manager for grid integration of renewable energy and onshore / offshore wind energy; Chairman of the German Offshore Committee
- 1989 – 2003: Federal Environmental Agency; Scientific assistant for offshore wind energy, offshore gas / oil exploration, pulp and paper industry, life cycle assessment
- 1989: Graduated as Engineer Environmental Protection Technology at Technical University of Berlin

Learning objectives

- A participant who has met the objectives of the course will be able to develop an interactive training session to
  - explain fundamentals of photovoltaic inverter technology to convert direct current (DC) to alternating current (AC)
  - explain voltage control concepts with PV
  - explain fundamentals of protection settings with PV

renac
renewables academy

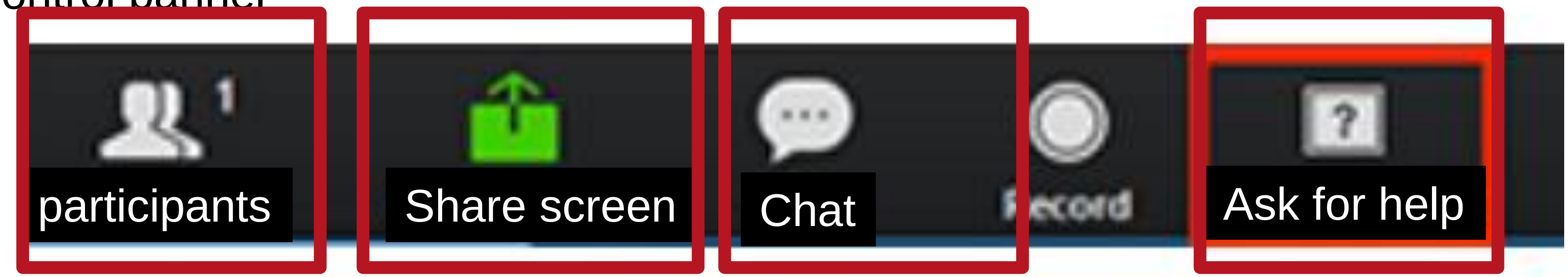
Interactive virtual classroom with breakout rooms for group work

For this training

1. Lecture in the ***virtual classroom*** with all participants
2. The participants will move to ***breakout rooms*** for group exercise
   - Solve the exercises in your group
   - Use the whiteboard, use the chat
   - Don‘t forget fo SAVE your results!
   - Every group chooses a presenter who presents the results in the classroom (share your screen)
3. The breakout rooms will end after a certain time and you will atomatically be in the ***virtuall classroom*** again
   - Participants present results in the virtual classroom with all participants
   - Discussion of results

Breakout room tools

- Control pannel



- Whiteboard

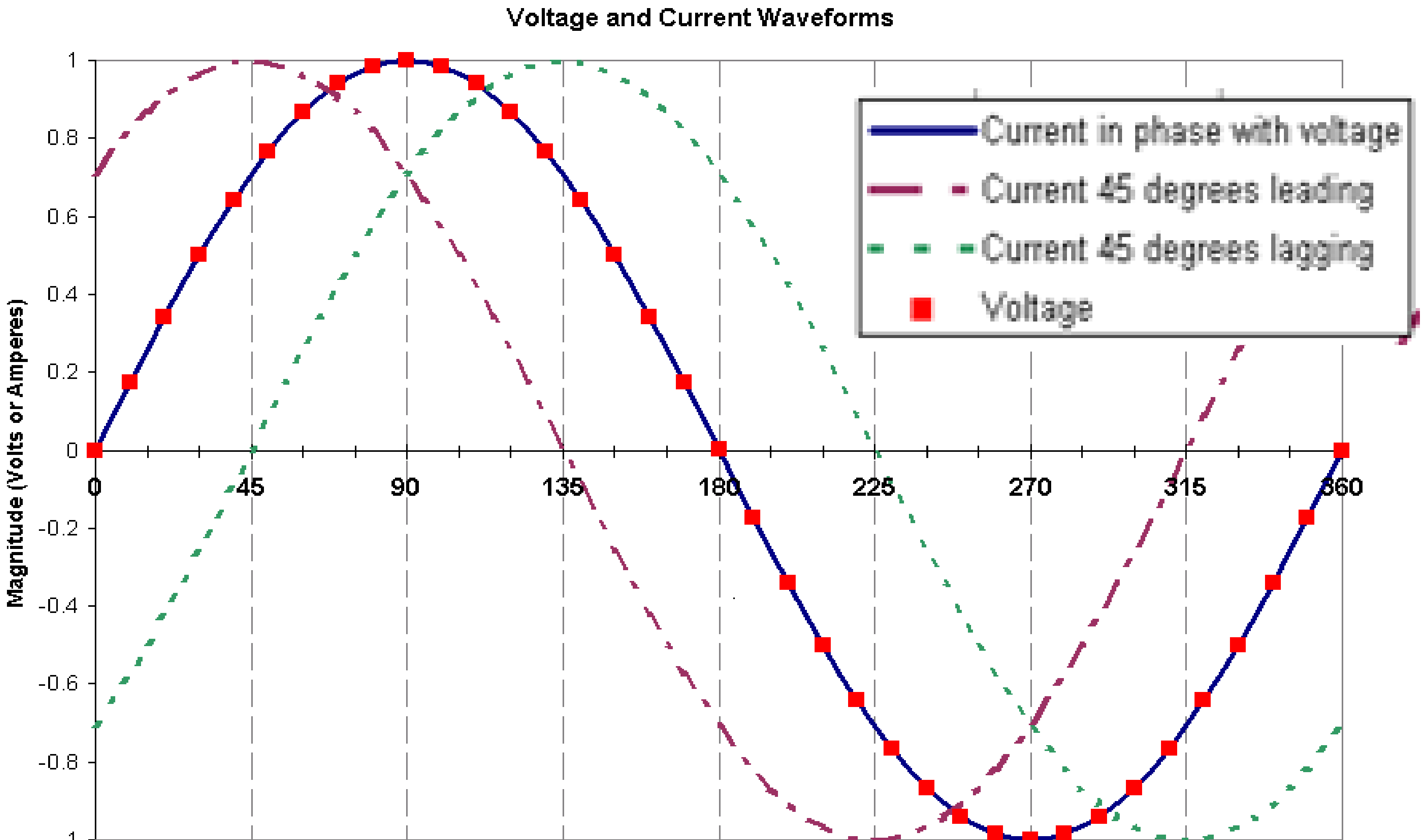
Voltage control concepts

Theory - active and reactive power

- Active power
  - The component of electric power that performs work, typically measured in kilowatts (kW) or megawatts (MW), also known as 'real power'
  - The terms 'active' or 'real' are used to modify the base term 'power' to differentiate it from reactive power
  - Active power accomplishes useful work (e.g. runs motors and lights lamps)
- Reactive power
  - The portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. Reactive power must be supplied to most types of magnetic equipment, such as motors and transformers
  - Reactive power is provided by generators, synchronous condensers, or electrostatic equipment such as capacitors. It directly influences electric system voltage
  - Kilovolt-amperes reactive (kVAR) or megavolt-ampere reactive (MVAR)

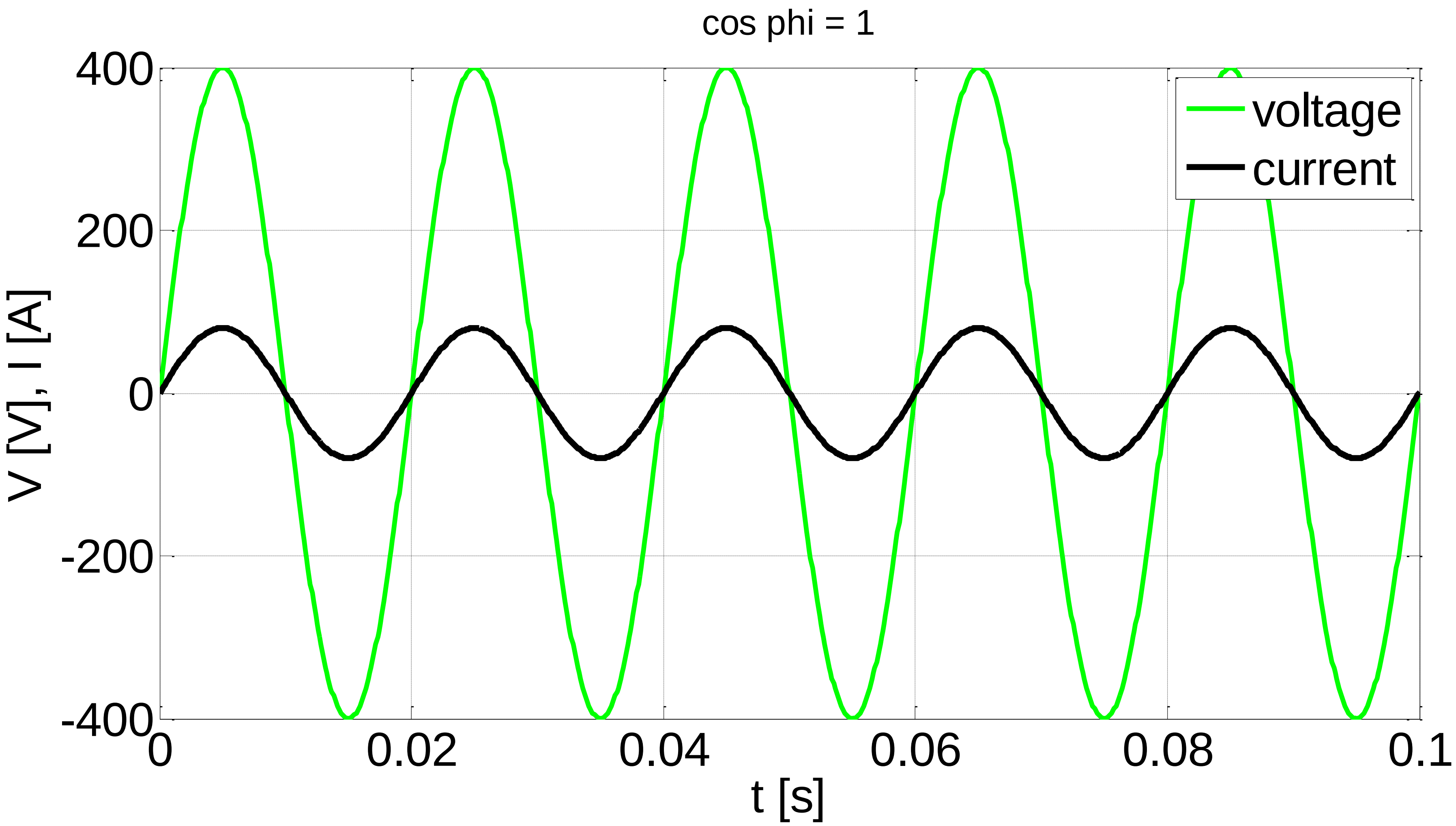
Source: www.eia.doe.gov/glossary/glossary_r.htm

Theory - voltage and current phase relationship

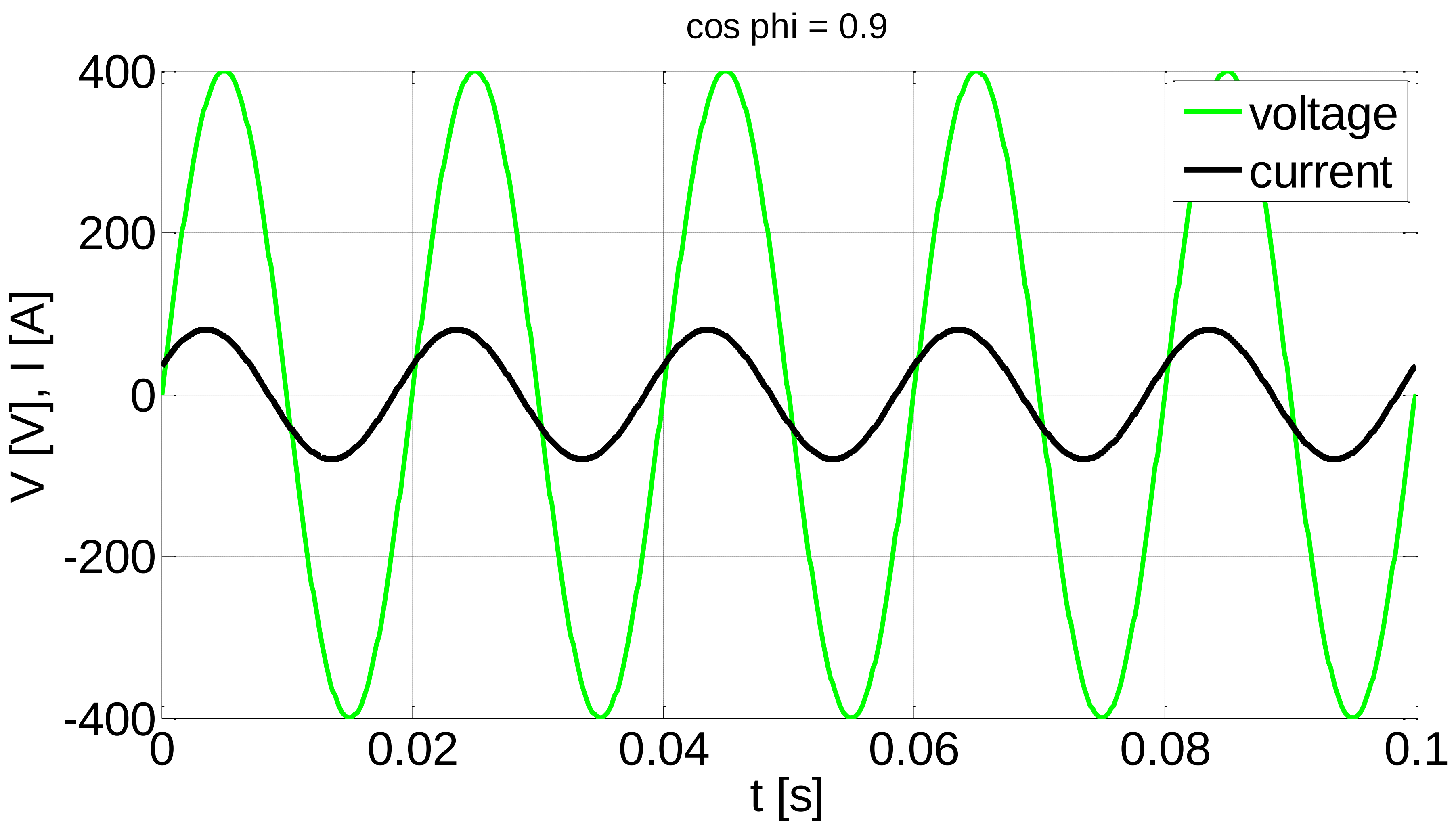


Source: http://www.ferc.gov/eventcalendar/files/20050310144430-02-04-05-reactive-power.pdf, 2009

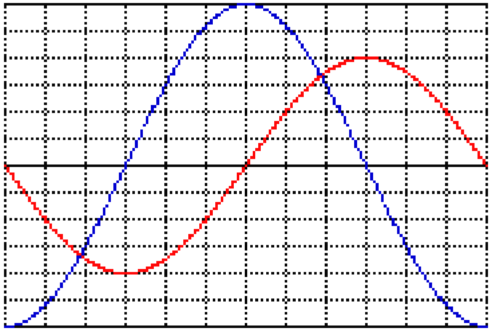
What does reactive power injection mean?

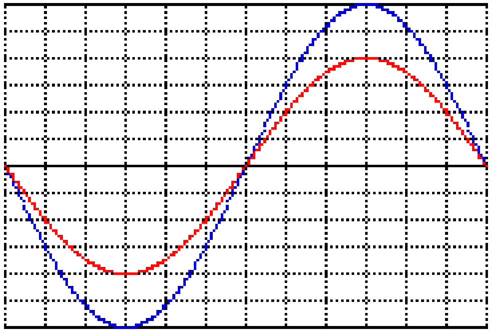


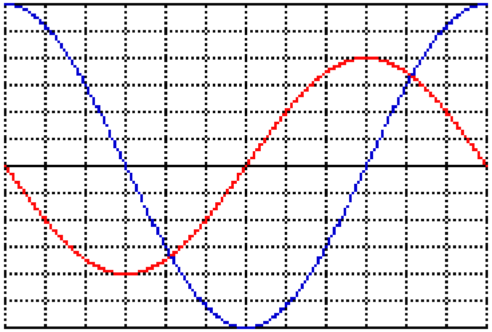
What does reactive power injection mean?



Exercise: Voltage and current phases



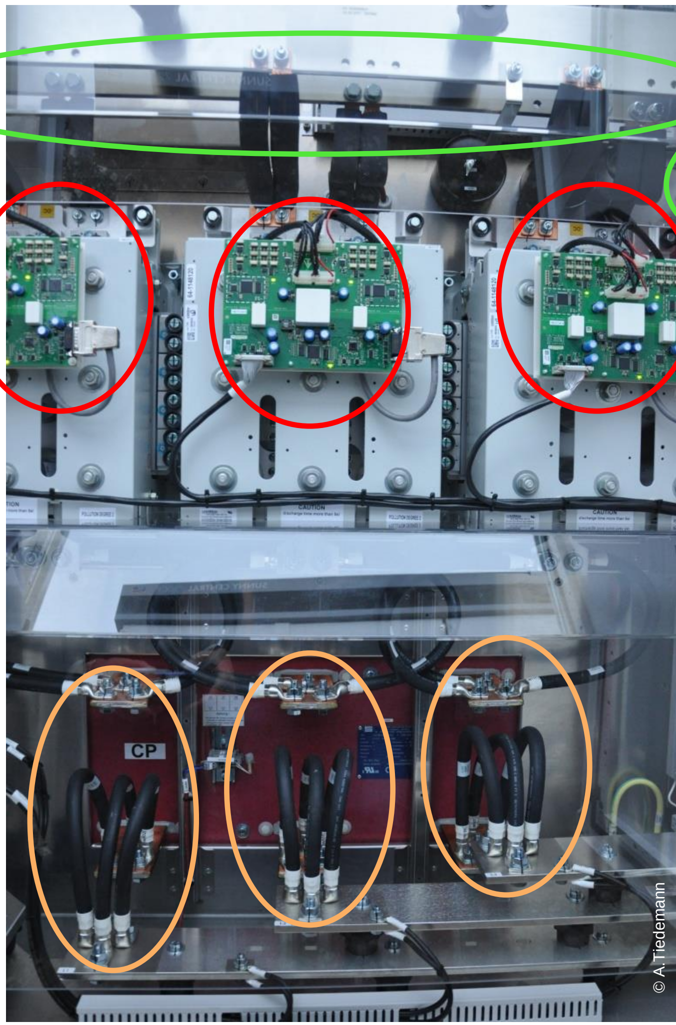


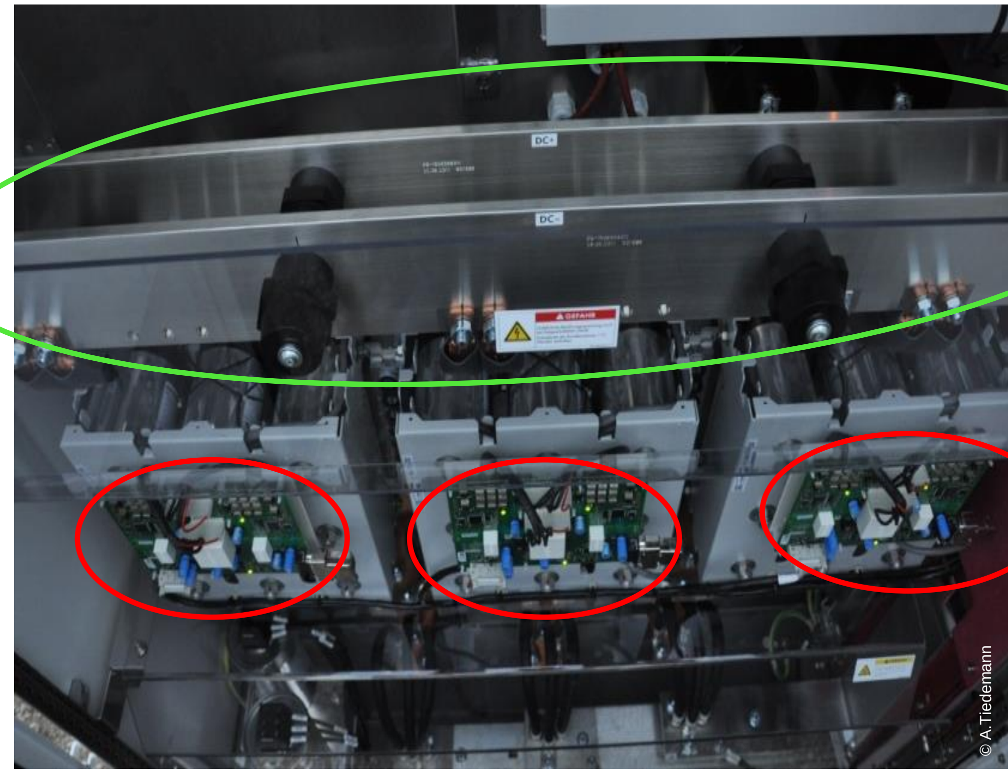


- Which diagram shows:
  - ☐ Current in phase with voltage
  - ☐ Current leading the voltage
  - ☐ Current lagging the voltage

Inverter technology - voltage control

Central SMA inverter: Direct current (DC), IGBTs (insulated gate bipolar transistor) and alternating current (AC)



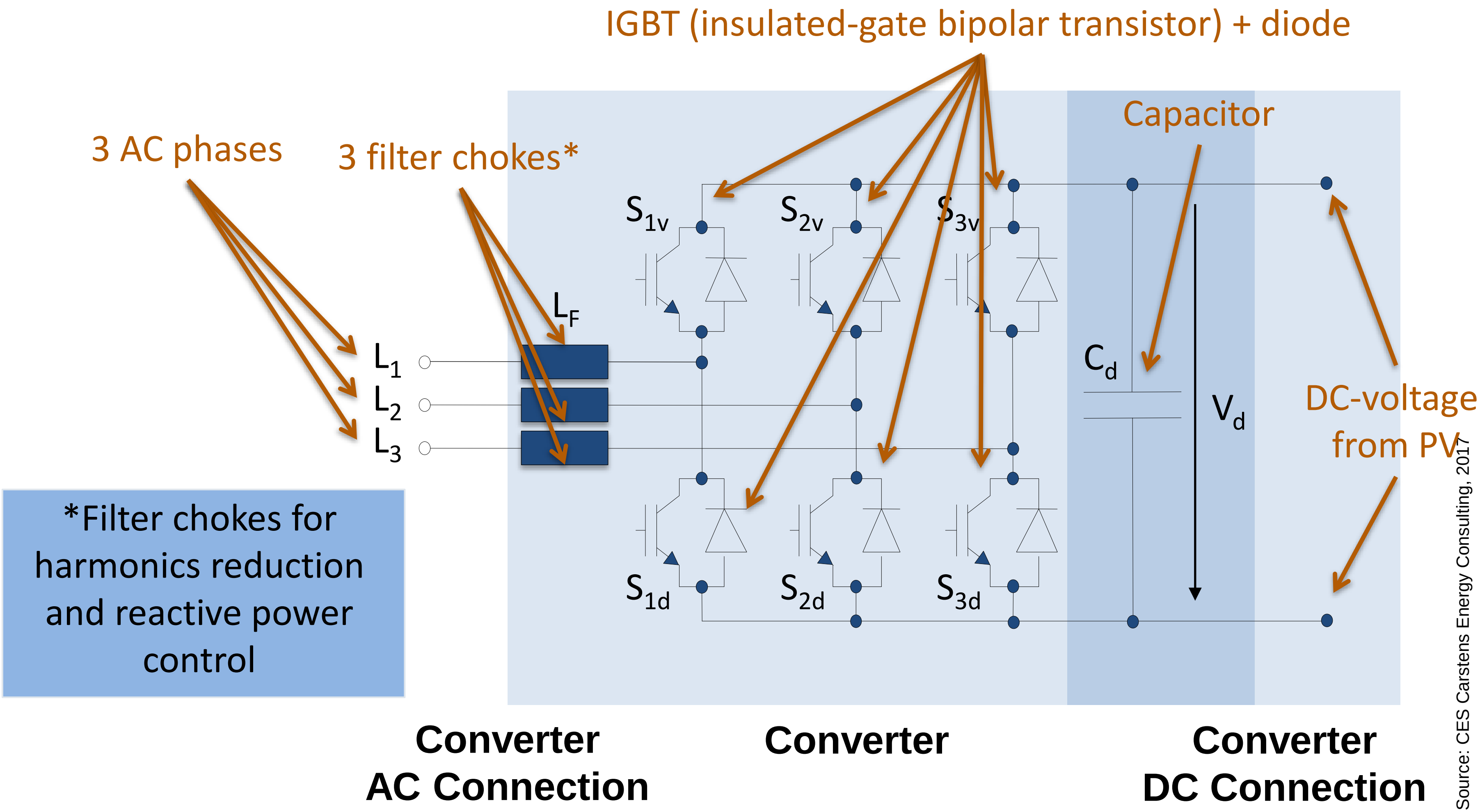


DC input to IGBT

IGBT (insulated-gate bipolar transistor)

AC output from IGBT

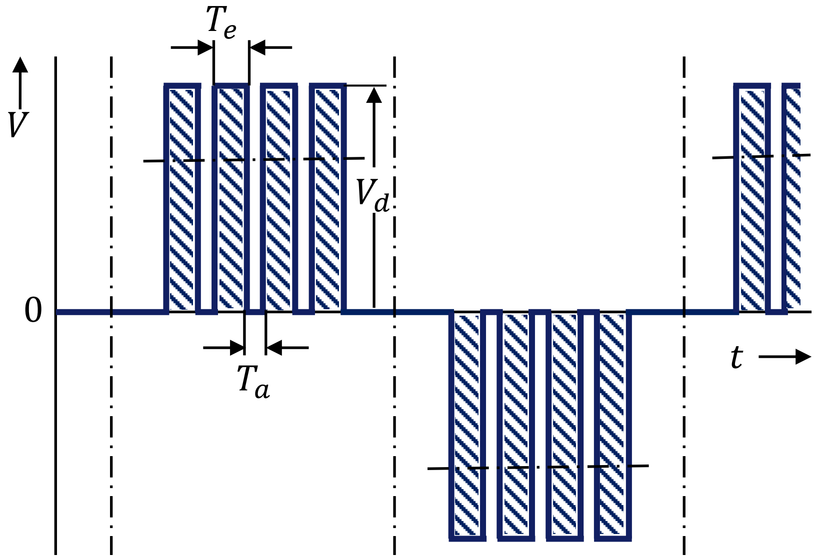
3 Phase converter design - from DC do AC

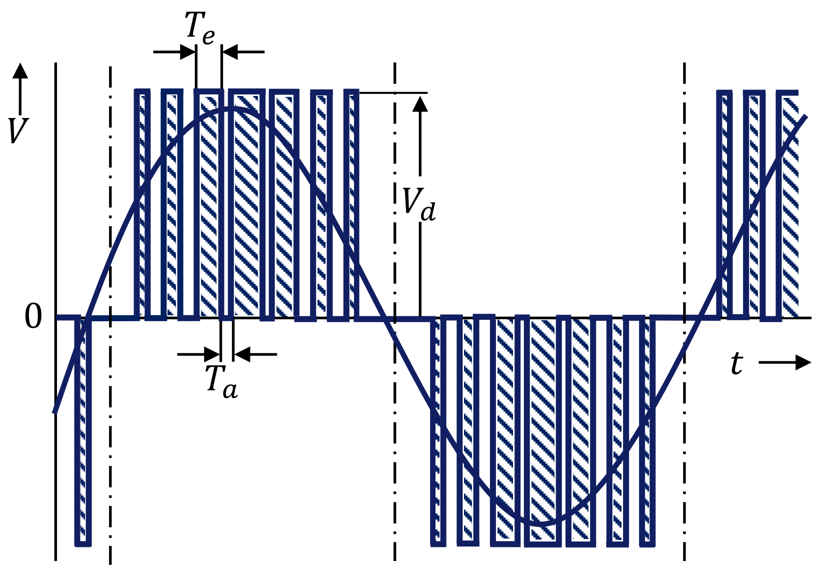


Source: CES Carstens Energy Consulting, 2017

Fundamental Voltage in Pulse Wide Modulation (PWM) – from DC to AC

renac renewables academy





- Switched on: T_e
- Switched off: T_a
- $T_e + T_a = T$
- Rectangular voltage blocks with frequency 1/T

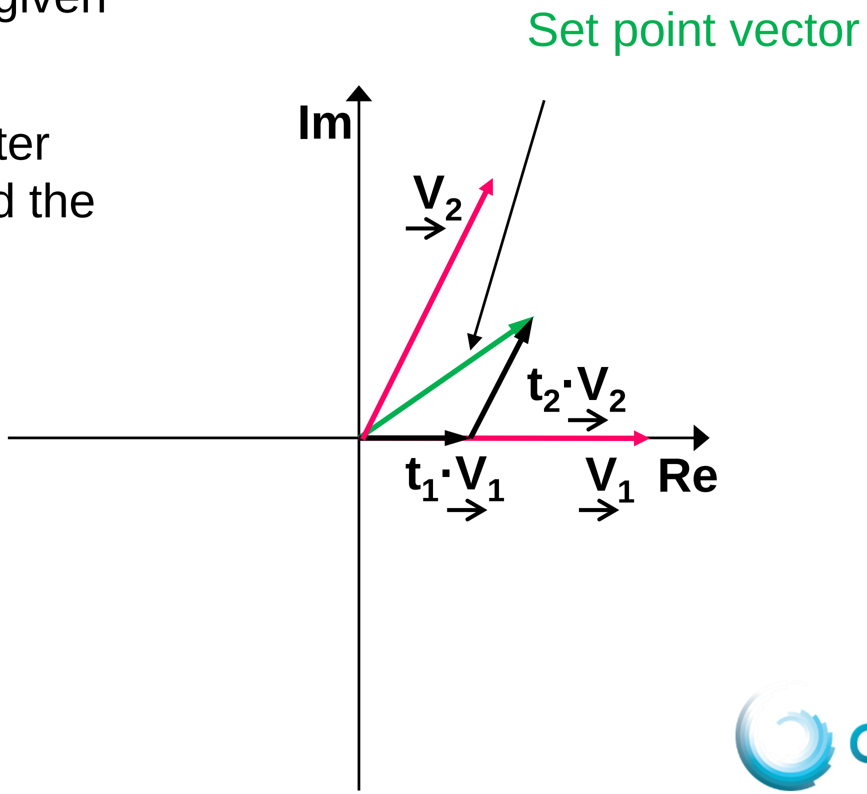
- Length of pulse changes voltage time area
- The longer switched on, the bigger voltage time area
- With pulse width modulation for every time step T effective voltage V_{C1} can be every voltage between $+V_d$ and $-V_d$
- Fundamental sinewave $V_{C,1}$ realizable

Source: Heumann: Grundlagen der Leistungselektronik
Source: CES Carstens Energy Consulting, 2017

Example: Control of amplitude and phase of voltage

- Phase and amplitude control of voltage with space vectors and switching times t_1 and t_2
- The converter calculates the switching time t_1 and t_2 for a given setpoint.
- For every time step the inverter can control the amplitude and the angle of the voltage.

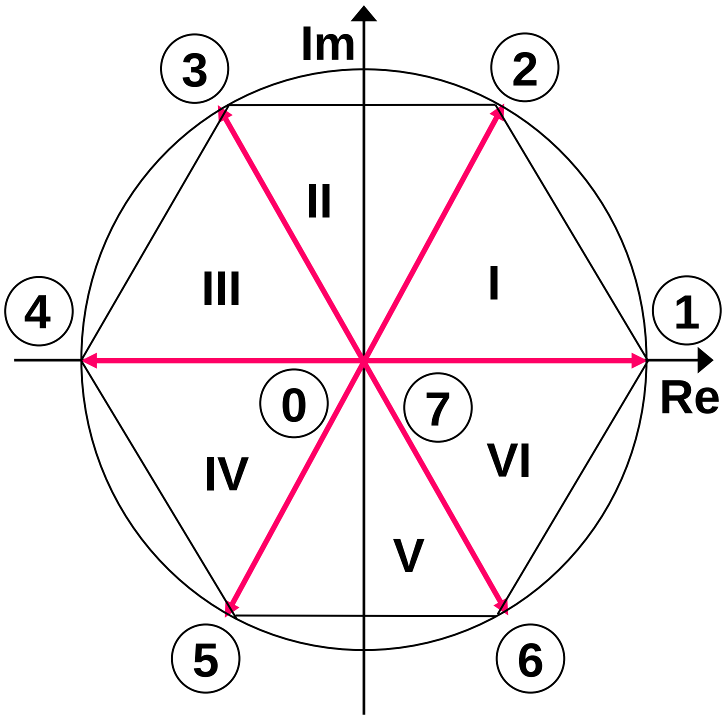
- t_1: Operation time vector V_1
- t_2: Operation time vector V_2



Source: CES Carstens Energy Consulting, 2017

3 Phase Space Vectors

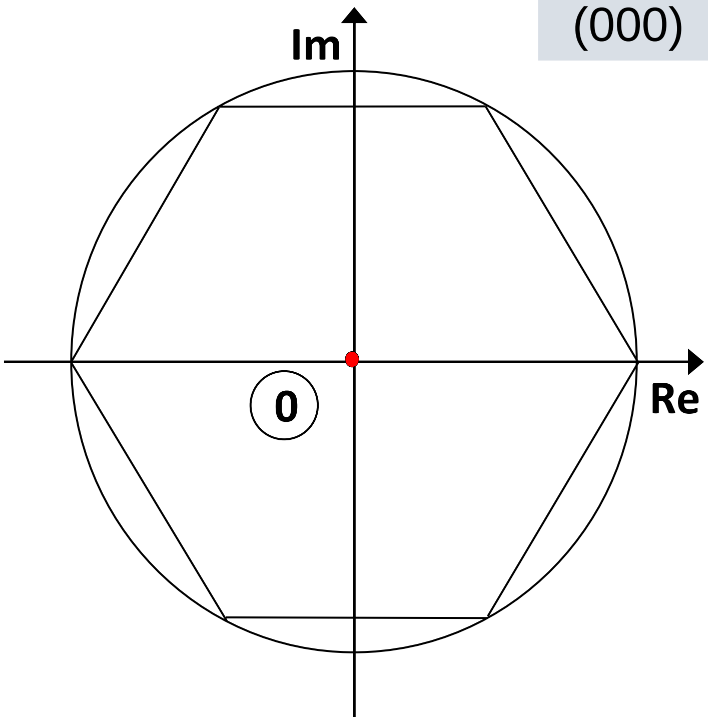
- Possible space vectors that a converter can produce by switching the IGBTs
- These space vectors are important to control the amplitude and the angle of the voltage.

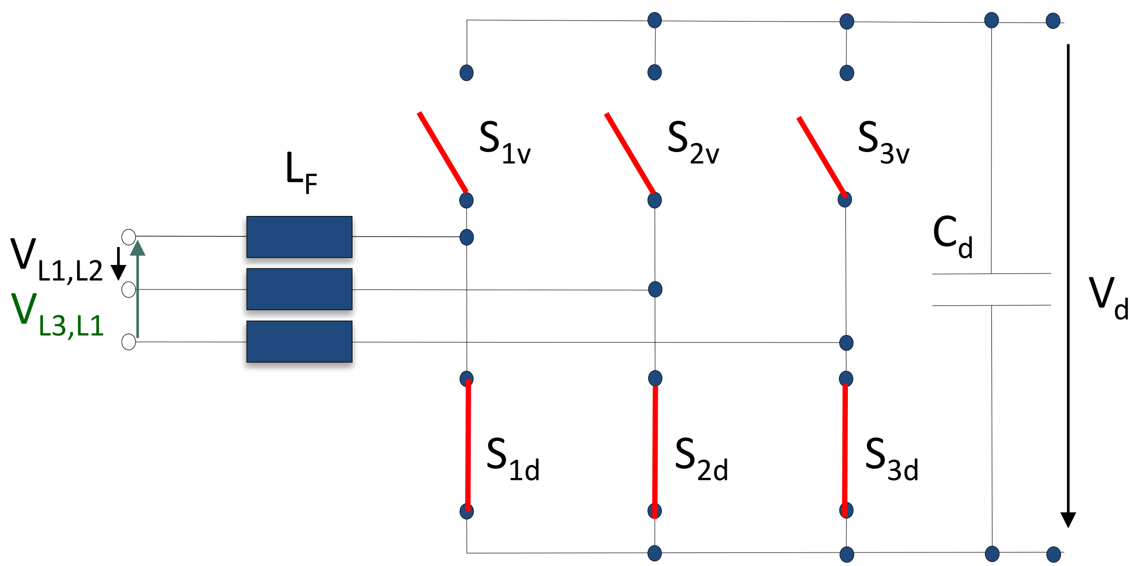


Source: CES Carstens Energy Consulting, 2017

Space Vector (000) Zero Vector

Space Vector	$V_{L1,L2}$	$V_{L2,L3}$	$V_{L3,L1}$	φ_{C1}	φ_{C2}	φ_{C3}
(000)	0	0	0	-	-	-

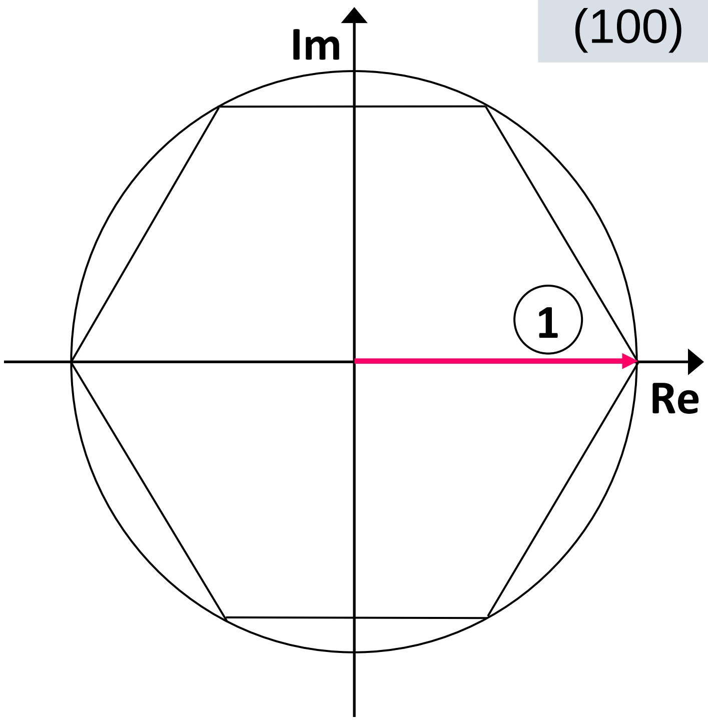


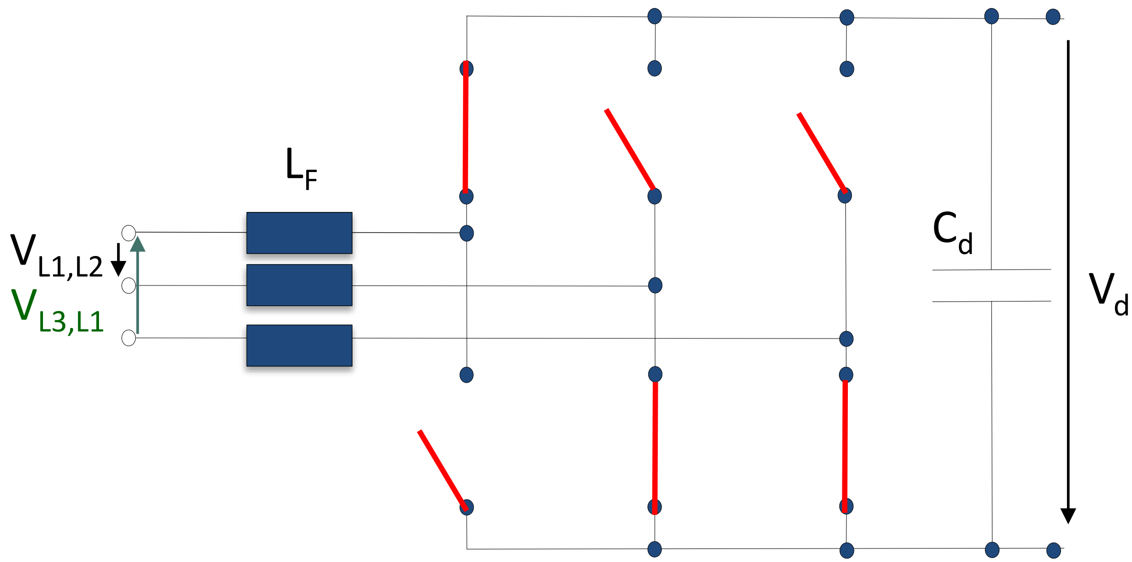


Source: CES Carstens Energy Consulting, 2018

Space Vector (100) Zero Vector

Space Vector	$V_{L1,L2}$	$V_{L2,L3}$	$V_{L3,L1}$	φ_{C1}	φ_{C2}	φ_{C3}
(100)	$+V_d$	0	$-V_d$	+	-	-

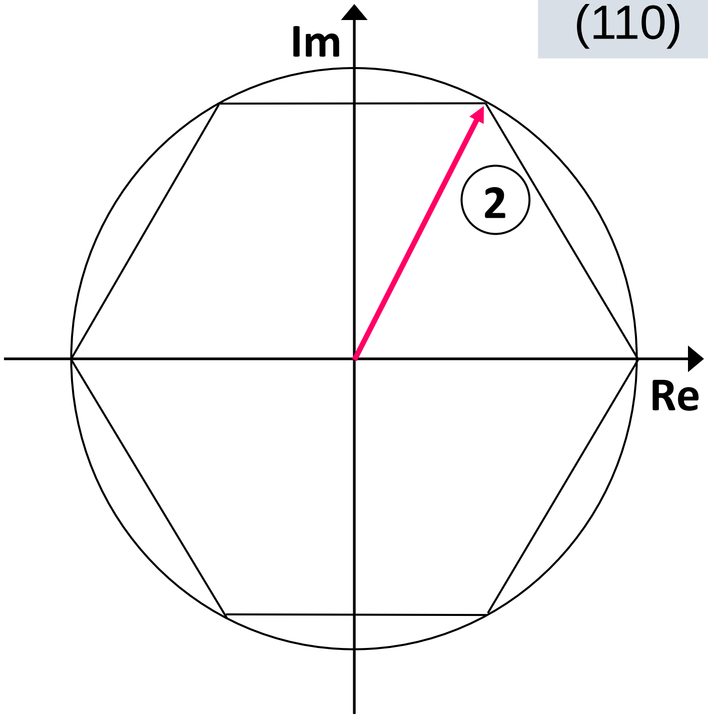


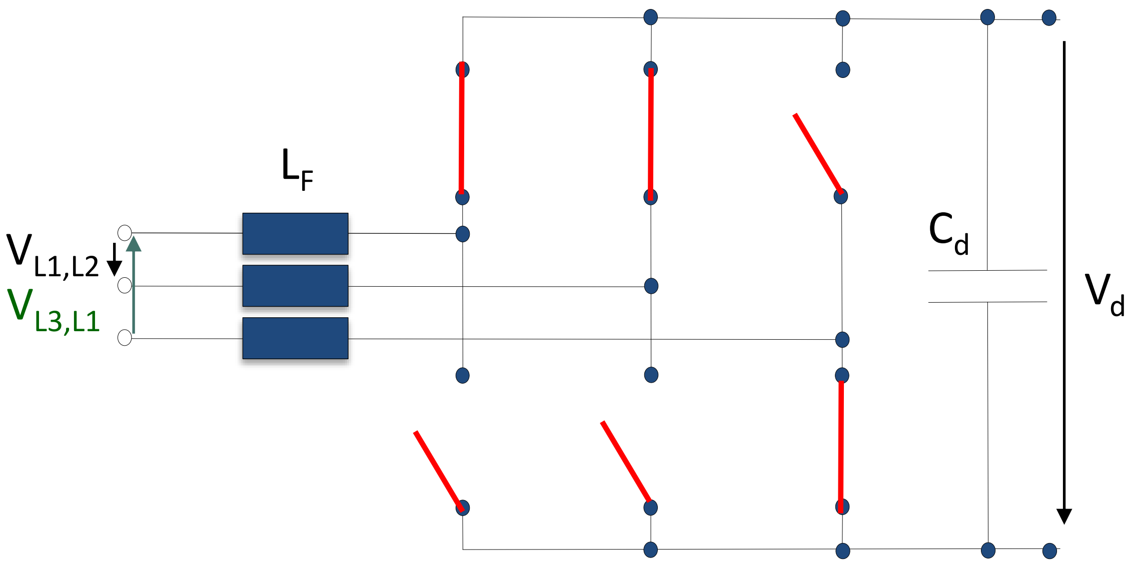


Source: CES Carstens Energy Consulting, 2018

Space Vector (110) Zero Vector

Space Vector	$V_{L1,L2}$	$V_{L2,L3}$	$V_{L3,L1}$	φ_{C1}	φ_{C2}	φ_{C3}
(110)	0	$+V_d$	$-V_d$	+	+	-

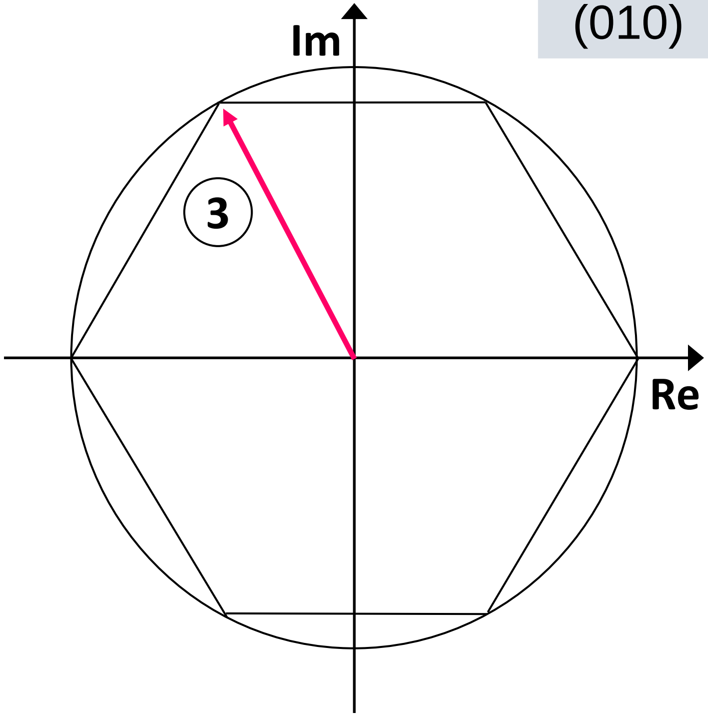


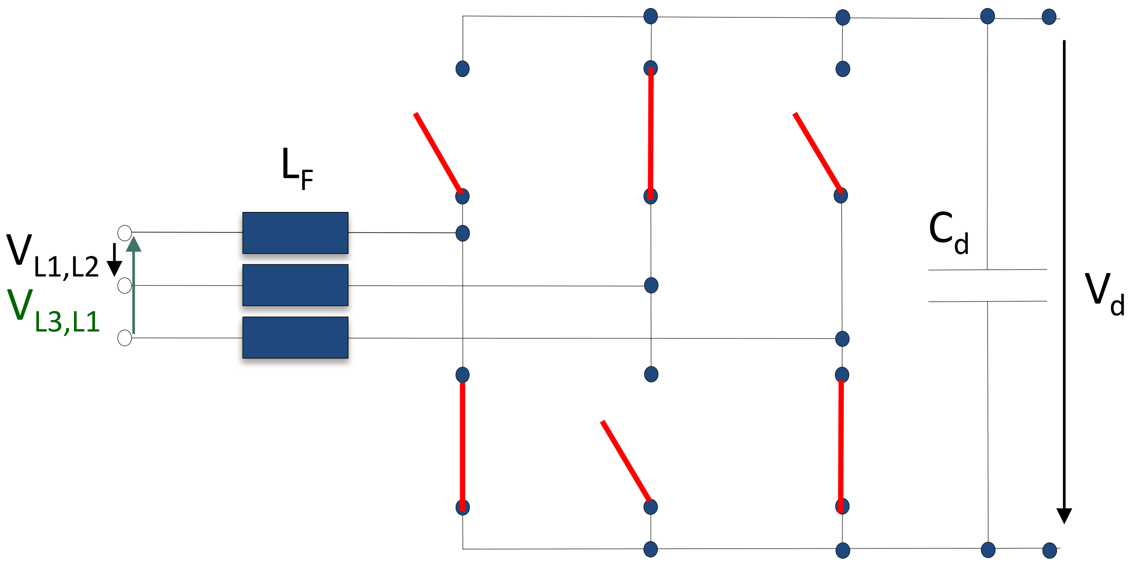


Source: CES Carstens Energy Consulting, 2018

Space Vector (010) Zero Vector

Space Vector	$V_{L1,L2}$	$V_{L2,L3}$	$V_{L3,L1}$	φ_{C1}	φ_{C2}	φ_{C3}
(010)	$-V_d$	$+V_d$	0	-	+	-

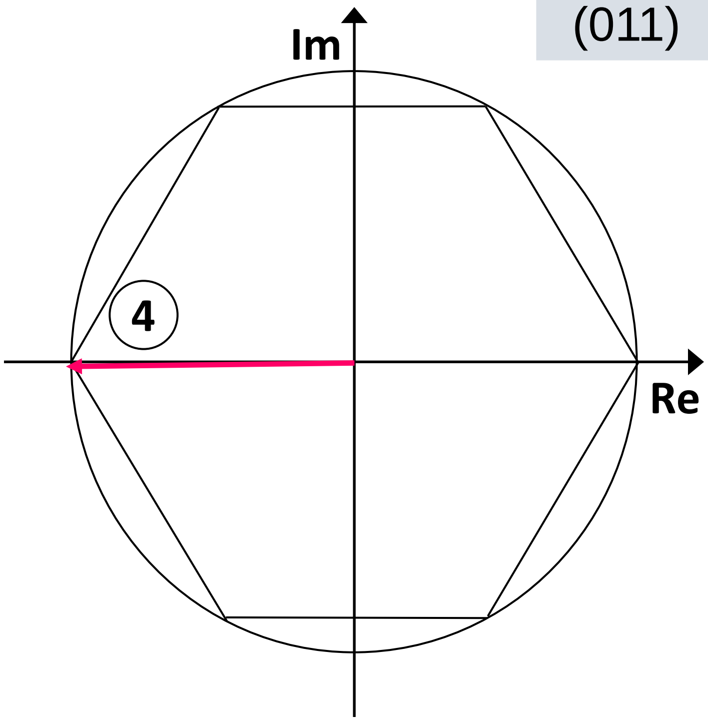


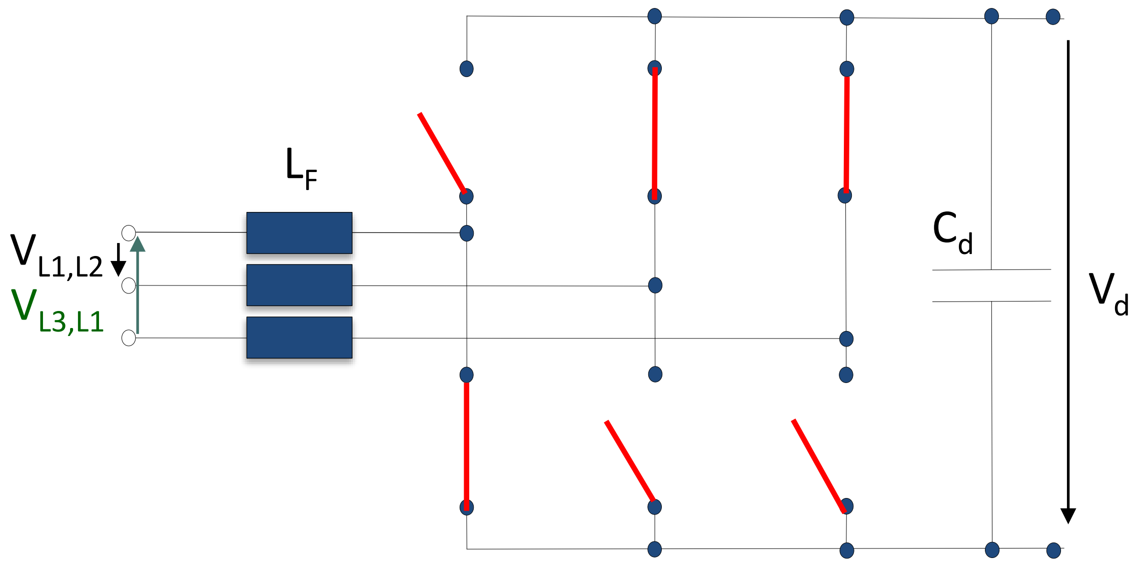


Source: CES Carstens Energy Consulting, 2018

Space Vector (011) Zero Vector

Space Vector	$V_{L1,L2}$	$V_{L2,L3}$	$V_{L3,L1}$	φ_{C1}	φ_{C2}	φ_{C3}
(011)	$-V_d$	0	$+V_d$	-	+	+

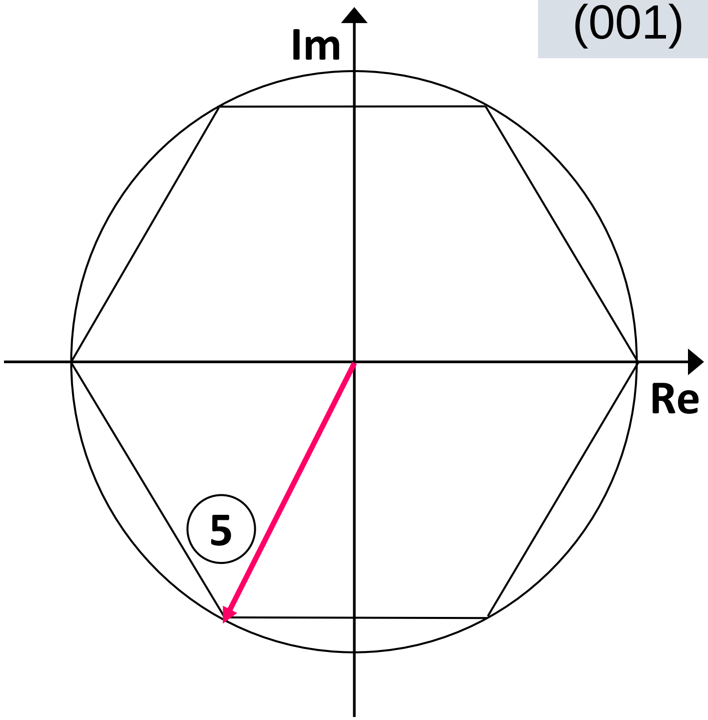


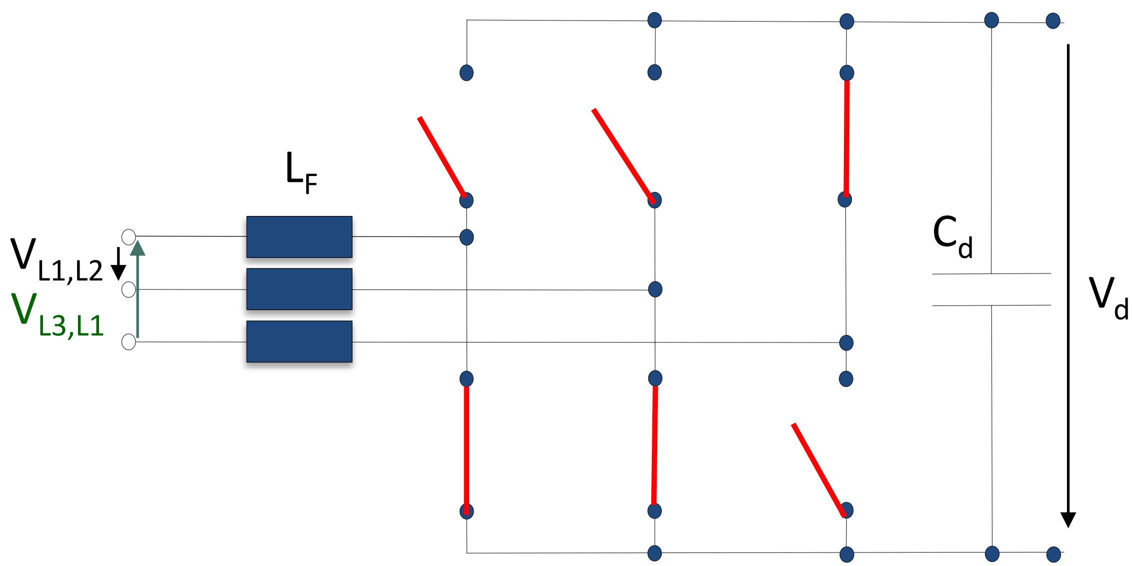


Source: CES Carstens Energy Consulting, 2018

Space Vector (001) Zero Vector

Space Vector	$V_{L1,L2}$	$V_{L2,L3}$	$V_{L3,L1}$	φ_{C1}	φ_{C2}	φ_{C3}
(001)	0	$-V_d$	$+V_d$	-	-	+

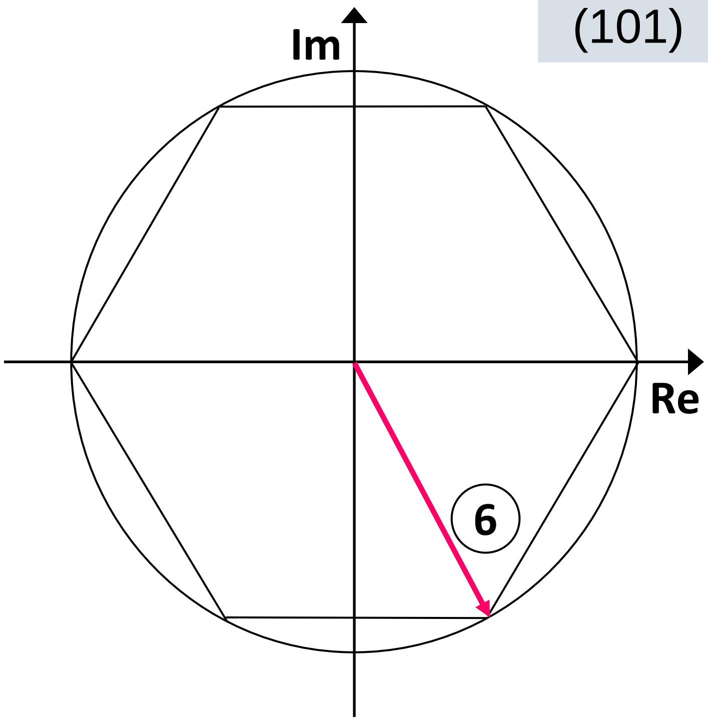


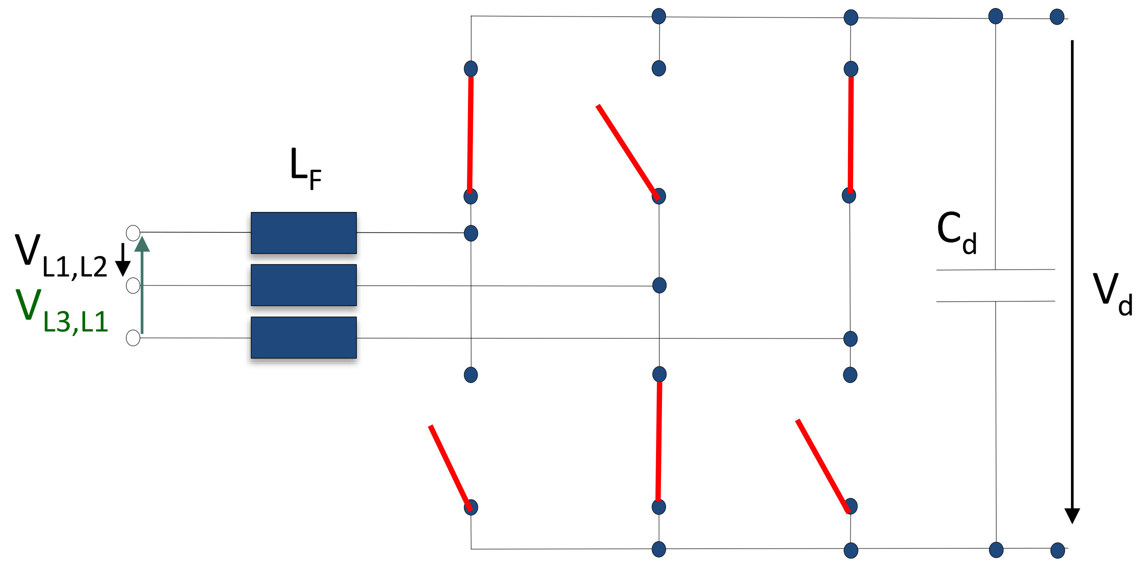


Source: CES Carstens Energy Consulting, 2018

Space Vector (101) Zero Vector

Space Vector	$V_{L1,L2}$	$V_{L2,L3}$	$V_{L3,L1}$	φ_{C1}	φ_{C2}	φ_{C3}
(101)	$+V_d$	$-V_d$	0	+	-	+

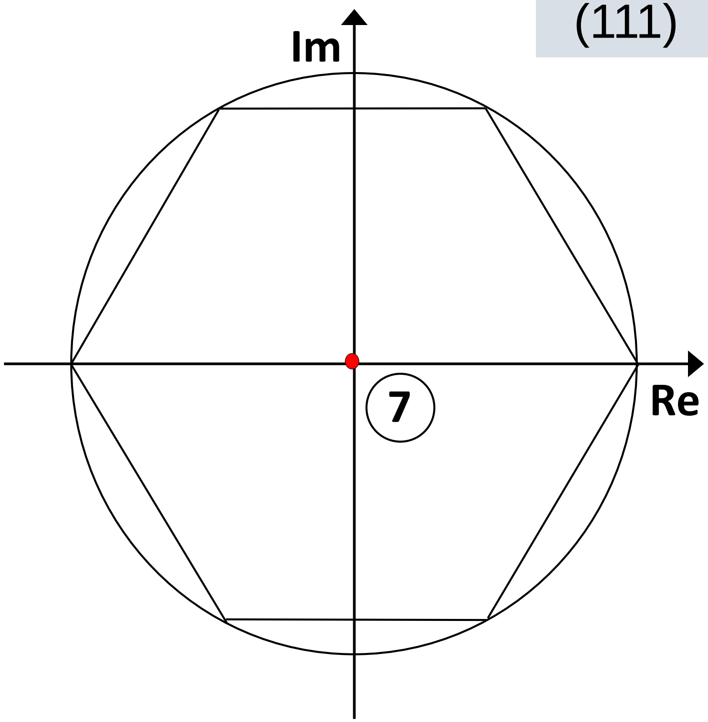


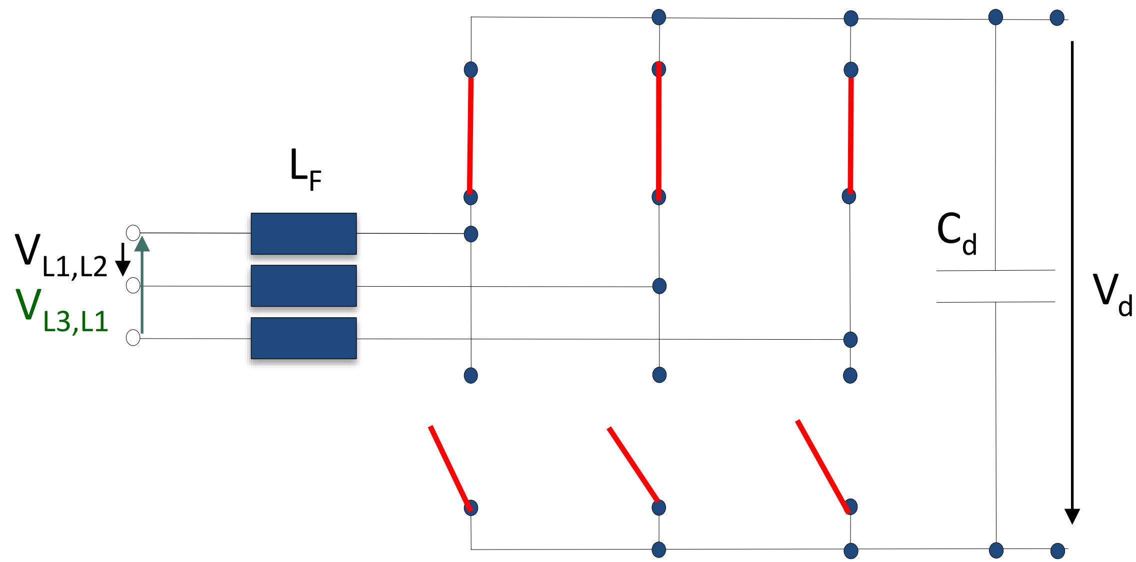


Source: CES Carstens Energy Consulting, 2018

Space Vector (111) Zero Vector

Space Vector	$V_{L1,L2}$	$V_{L2,L3}$	$V_{L3,L1}$	φ_{C1}	φ_{C2}	φ_{C3}
(111)	0	0	0	+	+	+

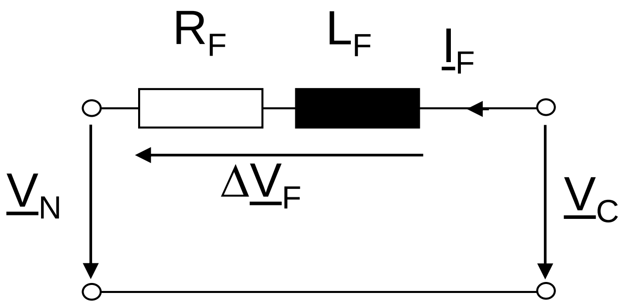




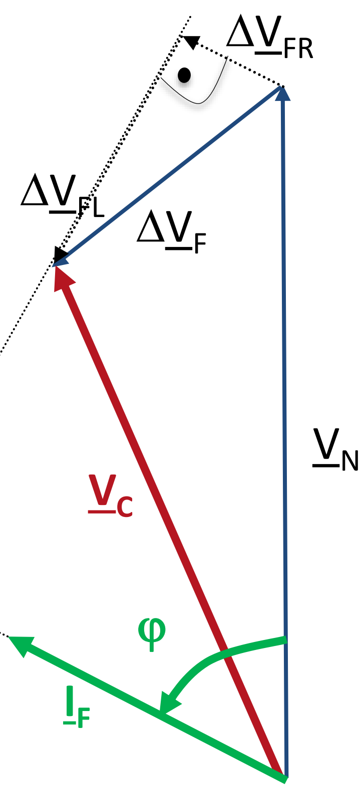
Source: CES Carstens Energy Consulting, 2018

Inverter technology - current and reactive power control

Current control mechanism at filter choke



- Choke L_F consists of real and imaginary component
- Voltage $\underline{V}_N = \underline{V}_{L1,L2}$ is instantaneous value of electrical grid
- Voltage $\underline{V}_C = \underline{V}_{C1,2}$ is instantaneous value of converter
- Mesh equation: $\underline{V}_C = \underline{V}_N + \Delta\underline{V}_F$
- $\underline{I}_F$ is 90 degrees lagging to imaginary component of $\Delta\underline{V}_F$ at L_F
- By control of $\underline{V}_C$ by PWM instantaneous value of $\underline{I}_F$ is controllable
- **Leading and lagging current is possible**
- **Magnitude of current is controllable**

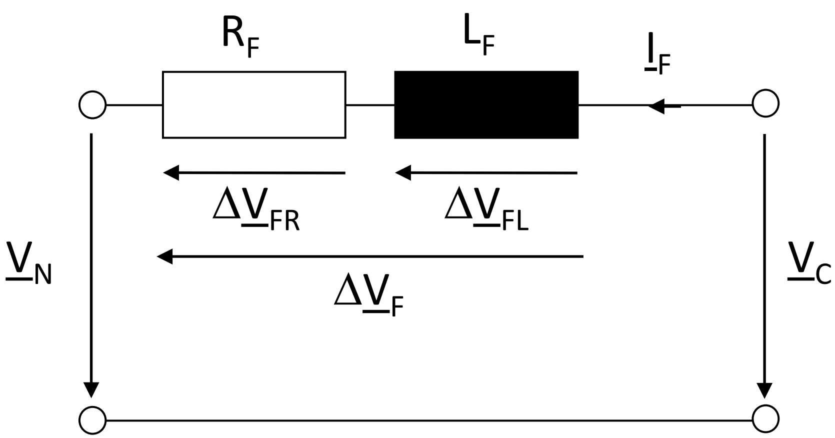


$\underline{V}_C$ = Converter voltage
$\underline{V}_N$ = Grid voltage
$\underline{I}_F$ = Current set point
ϑ = Phase angle set point

Source: CES Carstens Energy Consulting, 2017

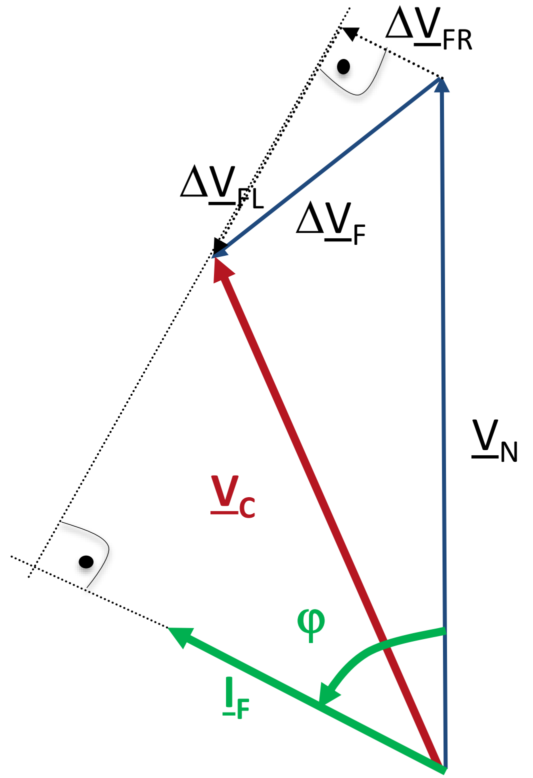
CES CARSTENS ENERGY SOLUTIONS

Current control I



- Mesh equation:
  $\underline{V}_C = \Delta\underline{V}_{FL} + \underline{V}_N + \Delta\underline{V}_{FR}$
- As differential equation:

$$V_C(t) = L_F \frac{di_F(t)}{dt} + V_N(t) + R_F i_F(t)$$



$\underline{V}_C$ = Converter voltage

$\underline{V}_N$ = Grid voltage

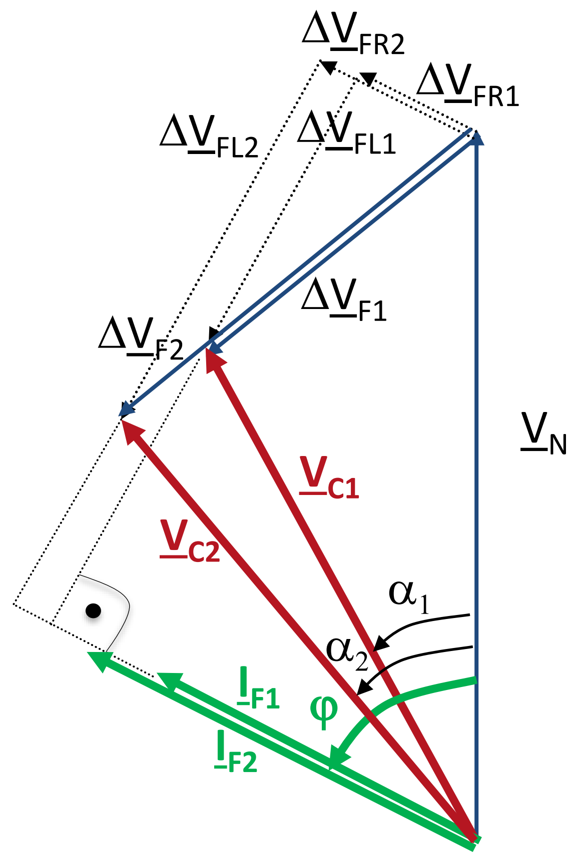
$\underline{I}_F$ = Current set point

ϑ = Phase angle set point

Source: CES Carstens Energy Consulting, 2017

Current control II

- Same current phase but different amplitude

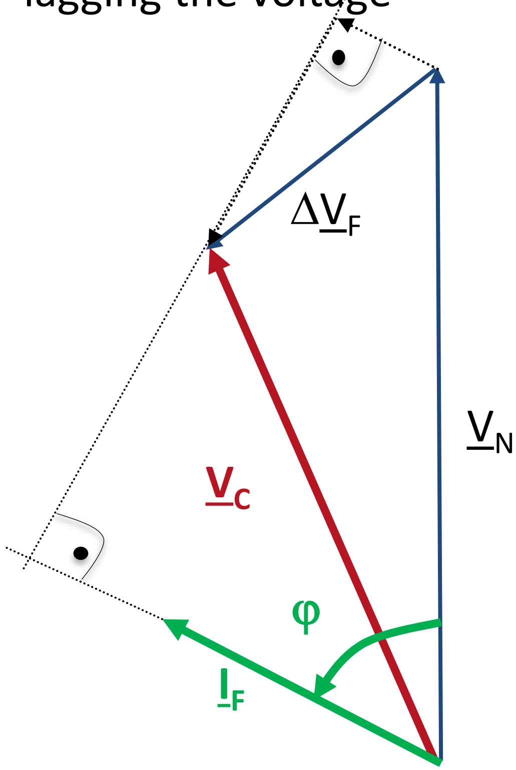


$\underline{V}_C$ = Converter voltage
$\underline{V}_N$ = Grid voltage
$\underline{I}_F$ = Current set point
ϑ = Phase angle set point

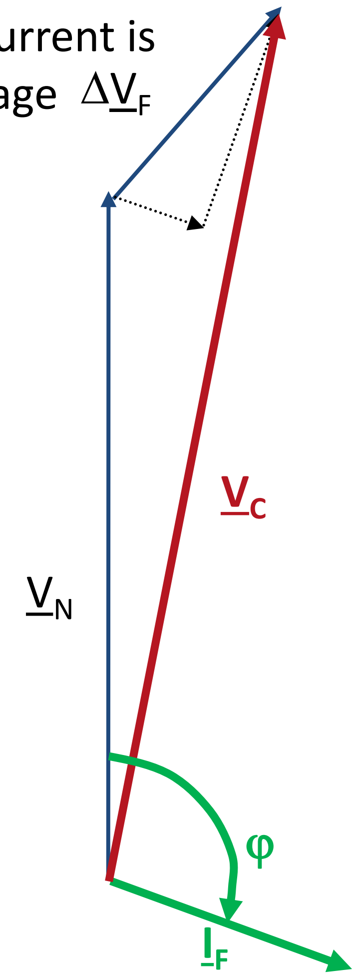
Source: CES Carstens Energy Consulting, 2017

Current control III

Inductive current: Current is lagging the voltage



Capacitive current: Current is leading the voltage



Source: CES Carstens Energy Consulting, 2017

renac
renewables academy

Static voltage control

Learning objectives

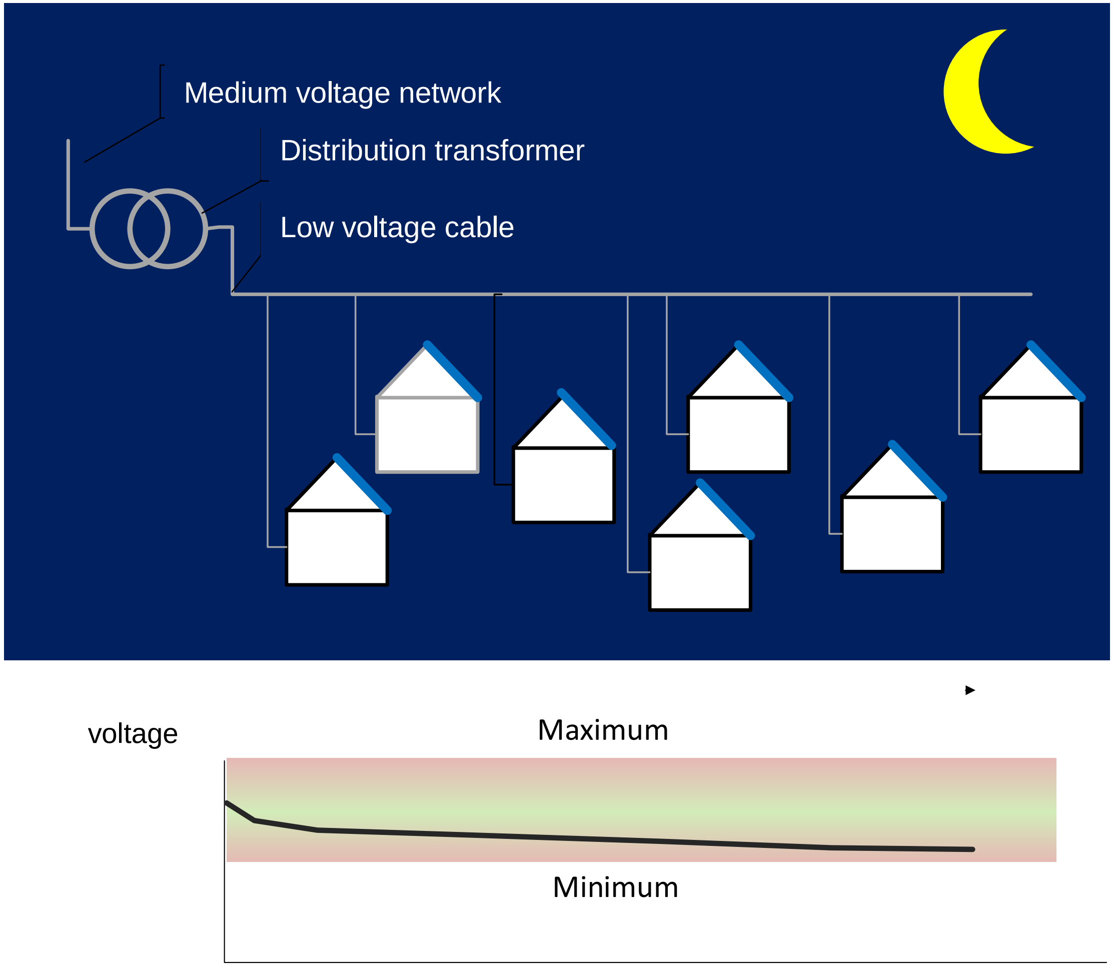
- After this lecture you will be able to
  - Name options for reactive power management with rooftop PV
  - Define power generating system (PGs) and power generating unit (PGU)
  - Explain rooftop PV reactive power generation Q(P) in low voltage grid
  - Explain rooftop PV reactive power generation Q(V) in low voltage grid
  - Distinguish benefits / drawbacks of influencing voltage by reactive power control

Learning objectives

Example: rooftop PV in low voltage distribution network – night.

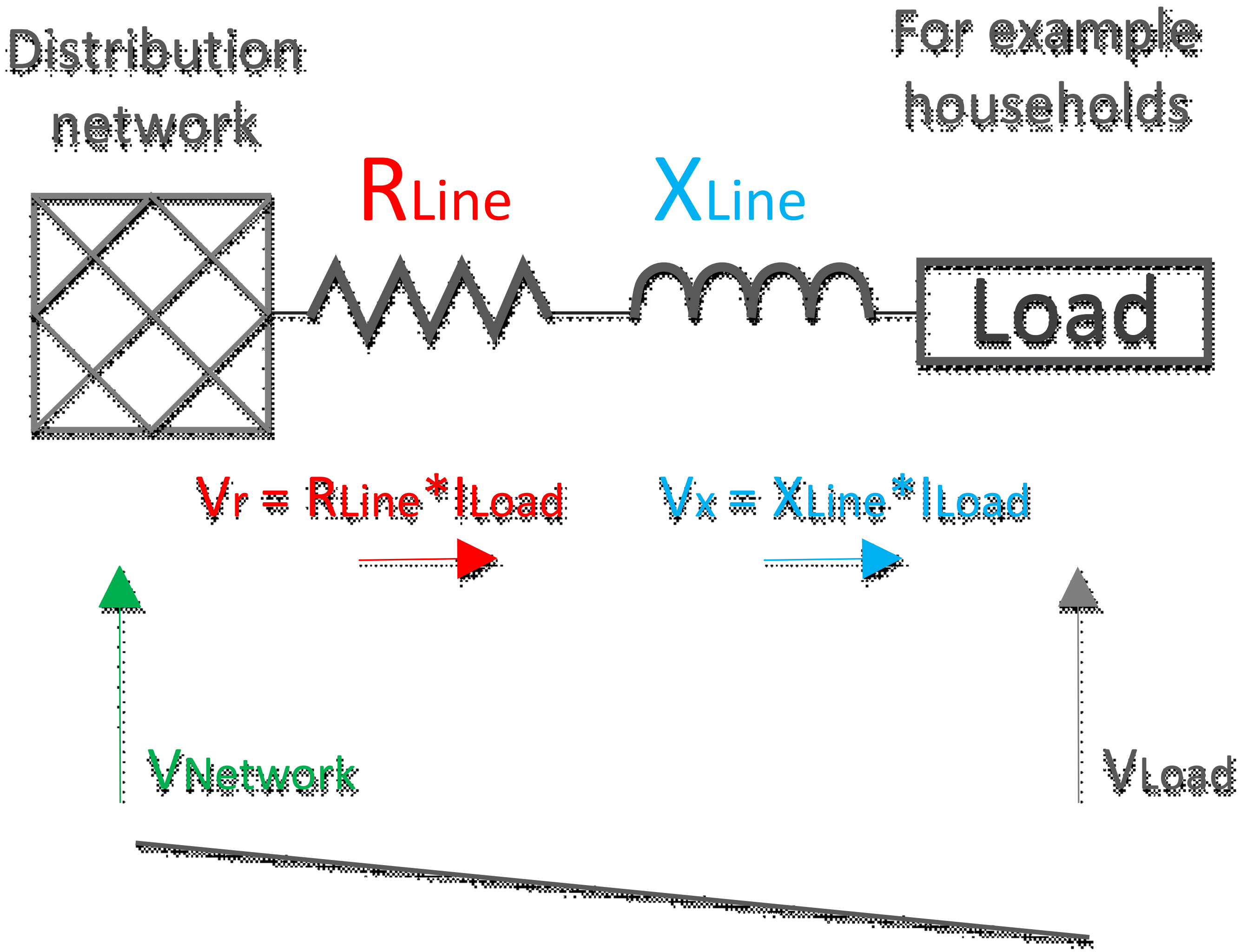
The tolerated voltage range may not be violated, regardless operational conditions.

Voltage at distribution transformer is set to a fixed value guaranteeing minimum voltage at the end of the line.



The current running via line resistance R and reactance X decreases voltage at the end of the line.

renac renewables academy



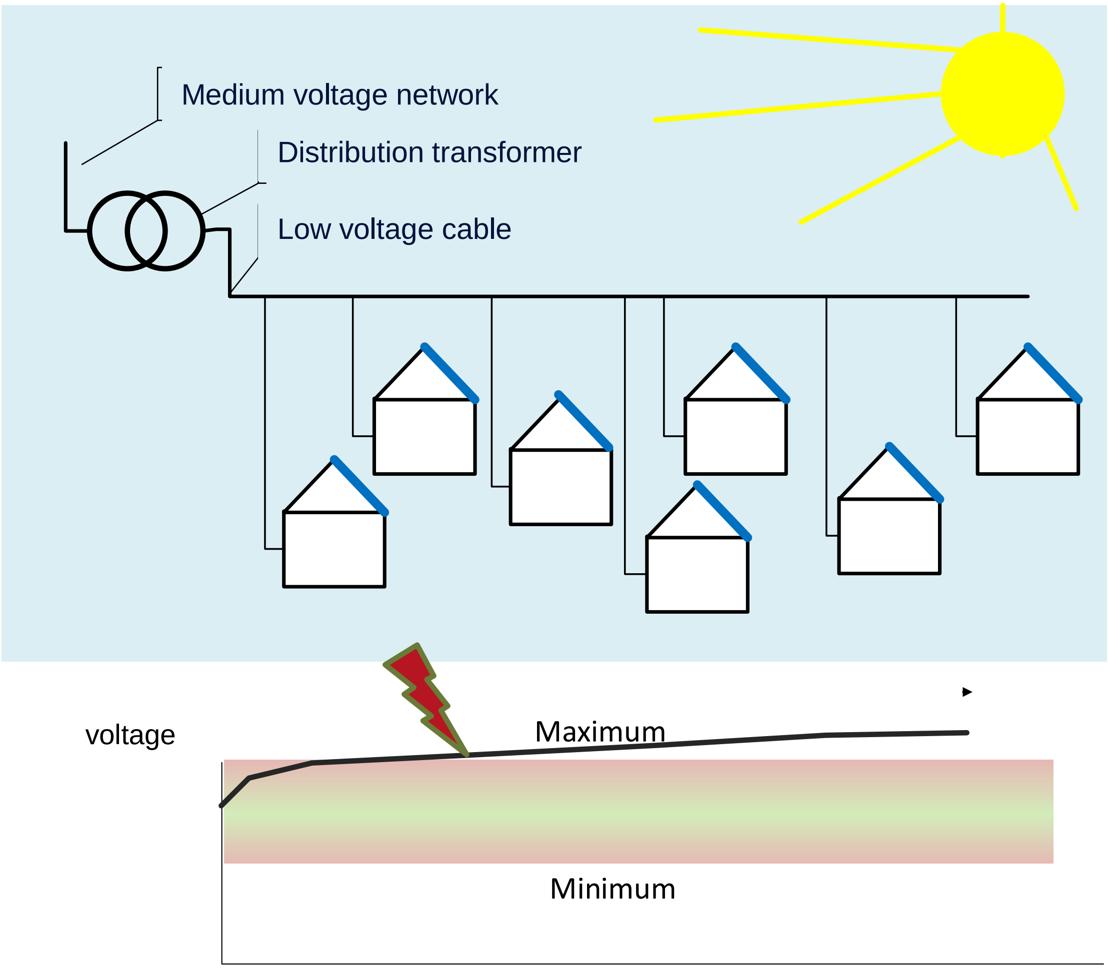
Source: Burges ReExpertise

Example: rooftop PV in low voltage distribution network – day.

renac renewables academy

In case of high feed in from PV this voltage setting violates tolerances at the end of the line.

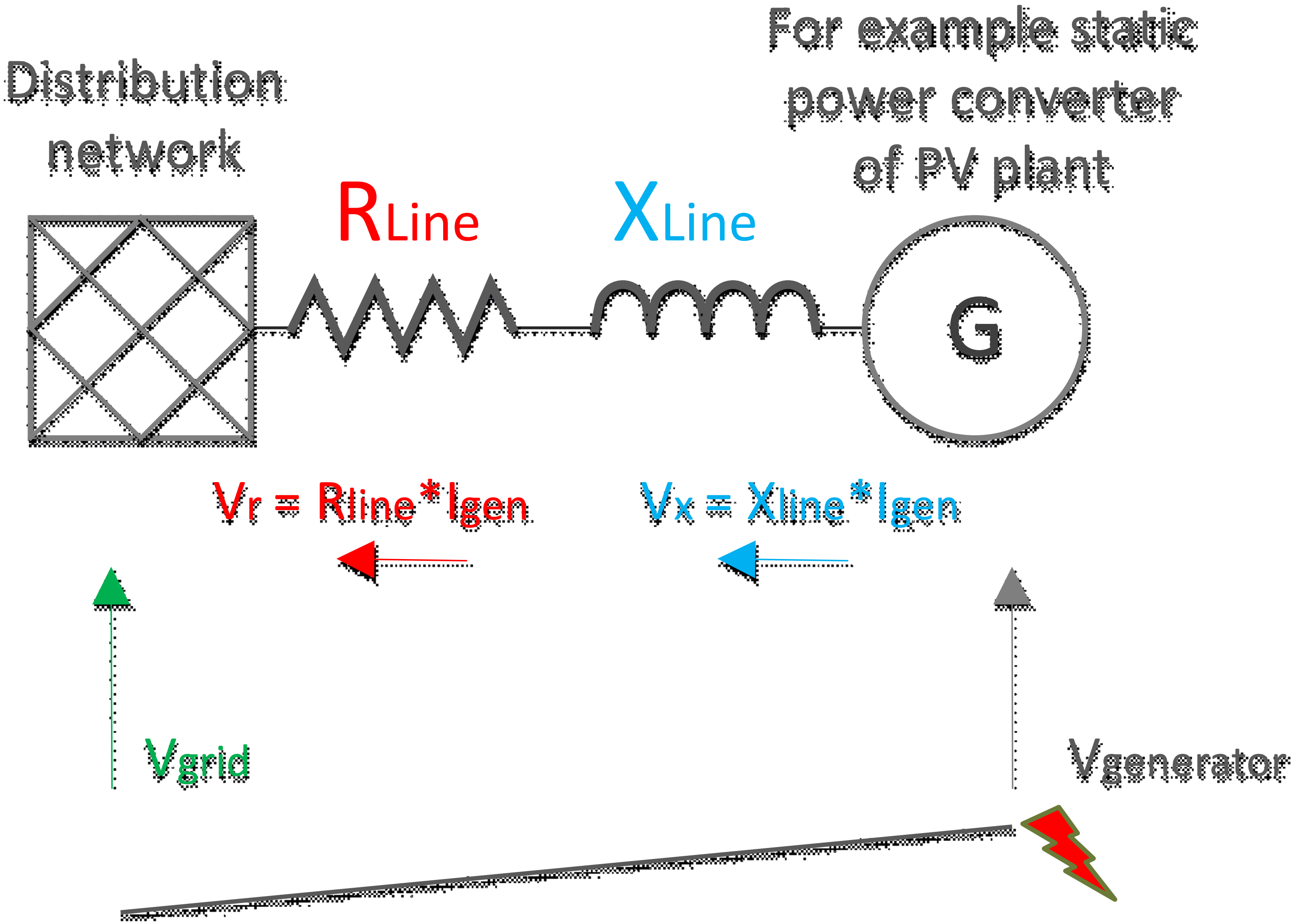
Load as well as PV generation are fluctuating. The voltage ranges become wider.



Effects in meshed networks (HV, EHV) with wind and or PV are similar.

However, more options exist to control voltage.

The current running via line resistance R and reactance X decreases voltage at the end of the line



Source: Burges ReExpertise

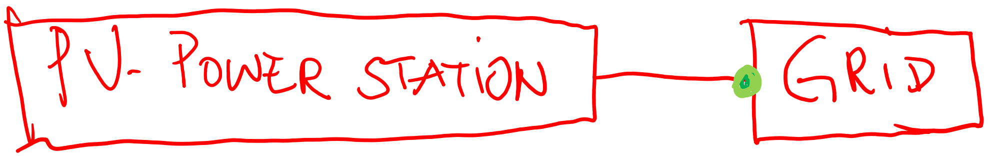
Options to handle overvoltage in distribution grids

renac
renewables academy

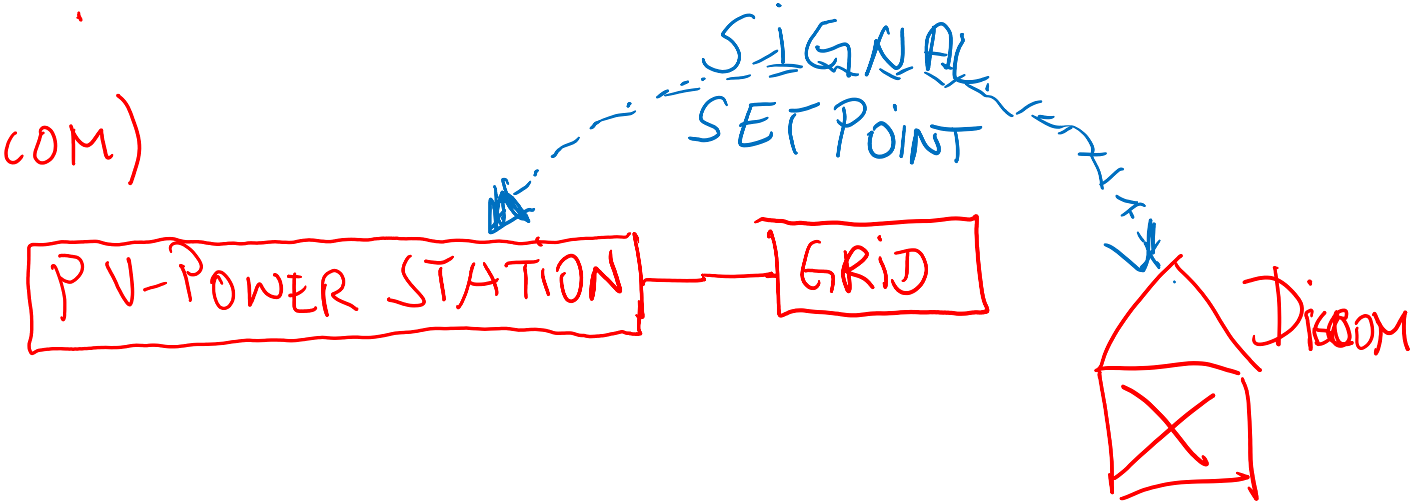
- Tolerated voltage levels may be violated by active power injection of distributed generators. This restricts feed in capacity.
- The simple alternatives are:
  - Curtailment of power infeed when voltage is too high.
    → Lost income for the owner of the generation plant and less clean energy.
  - Network reinforcement, step transformers, reducing the line resistance.
    → Extra investments for the owner of the network assets.
  - Reactive power management with distributed generation.
    → Use the features of modern PV inverters.

Reactive power management Q constant, Q(P), Q(V) and Q (discom)

- Q = constant   Q = reactive power
- Q (P)   Q DEPENDS OF ACTIVE POWER FEED-IN
- Q (V)   INVERTER MEASURES VOLTAGE AT GRID CONNECTION POINT AND CHANGES Q ACCORDINGLY



- Q (discom)



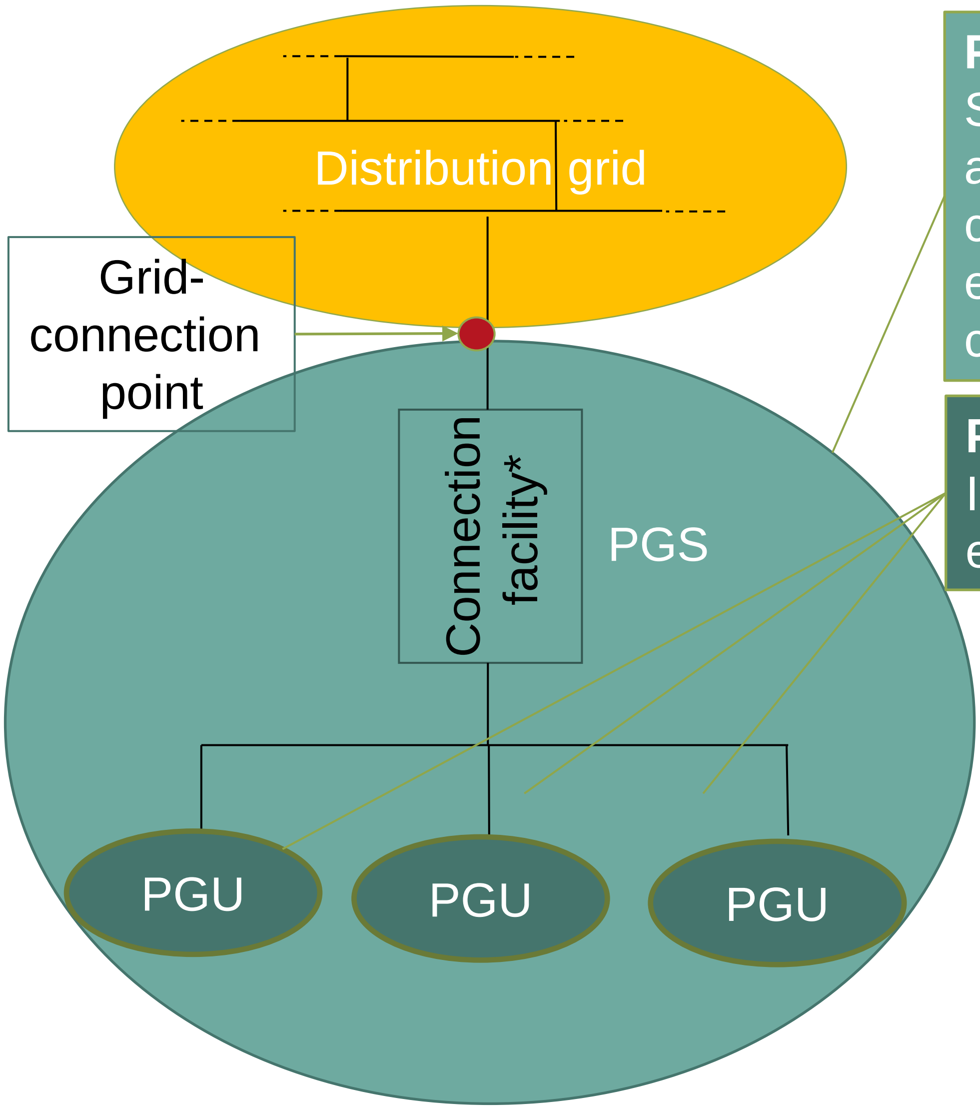
Monitoring system for PV (and other power plants connected to the grid)

Installed capacity	Fixed reduction of PV power generation in relation to installed capacity	Grid operator can reduce PV power feed-in	Real time PV feed-in data for grid operators	Additional data (plant, planning, non-usability, real time)[2)]
7 - 25 kW[1)]	< 70% installed kW or remote control[1)]		---	partly required
25 kW – 100 kW	---	required[1)]	required[1)]	partly required
100 kW – 1 MW	---	required	required	partly required
> 1 MW	---	required	required	required

Sources:
1) EEG 2021, §9 Nr. 2
2)Bundesnetzagentur, Beschlusskammer 6 „Festlegungsverfahren zur Informationsbereitstellung für Redispatch-Maßnahmen (BK6-20-061) – Anlage „Informationsbereitstellung für Redispatch-Maßnahmen“

Source: low voltage regulation E VDE-AR-N 4105:2017-07 (draft)

Definitions: power generating system (PGs) and power generating unit (PGU)



Power generating system (PGS): System in which one or more PGU´s are connected to the same network connection point, including all electrical installations necessary for connection and operation

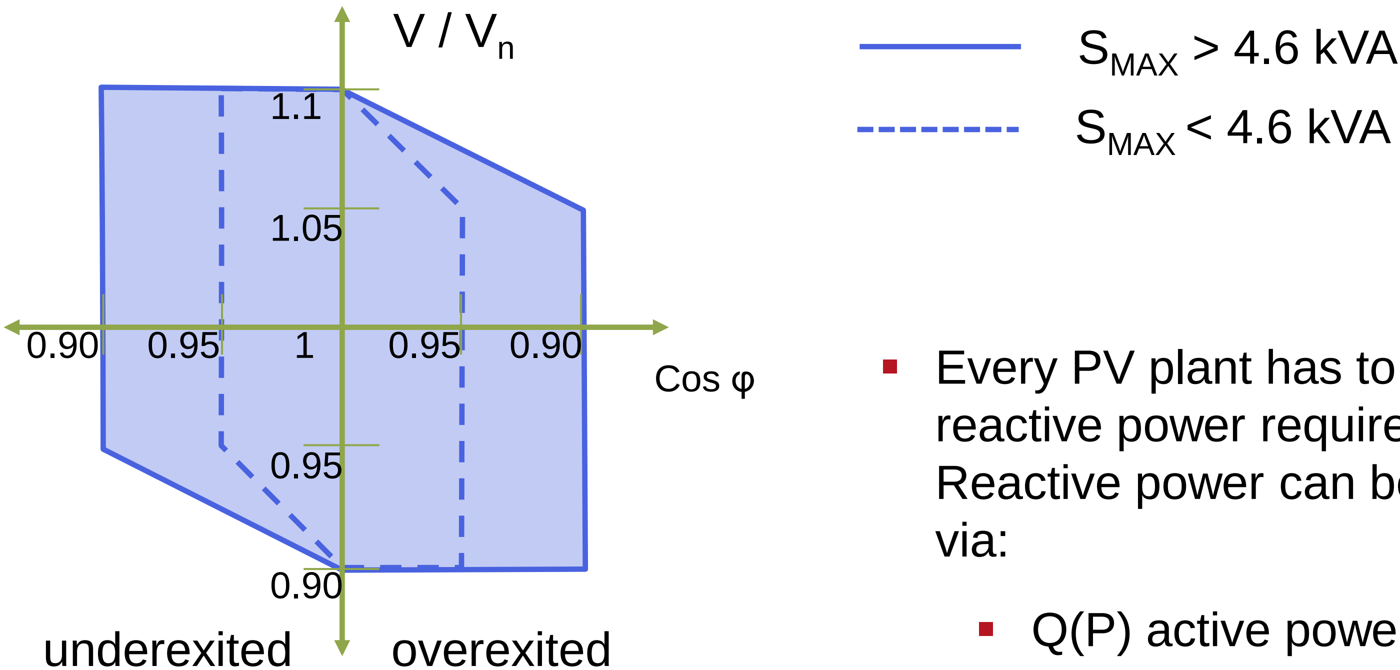
Power generating units (PGU): Individual unit for generating electrical energy

*) The connection facility usually consists of cable, transformers, coils, meter and transfer station

Abbreviations

- V_n = Nominal voltage [V]
- Q = reactive power [VAR]
- P = active power [W]
- S = apparent power [kVA]
- S_{Emax} = maximum apparent power of the unit (e.g. one PV-Inverter)
- S_{Amax} = maximum apparent power of the entire plant (plant with several PV-inverters)
- P_{Emax} = maximum active power of the unit (e.g. one PV-Inverter)
- P_{Amax} = maximum active power of the entire plant (plant with several PV-inverters)
- Low voltage grid < 1 kV
- Medium voltage grid 1 kV < 60 kV

Reactive power generation in low voltage grids

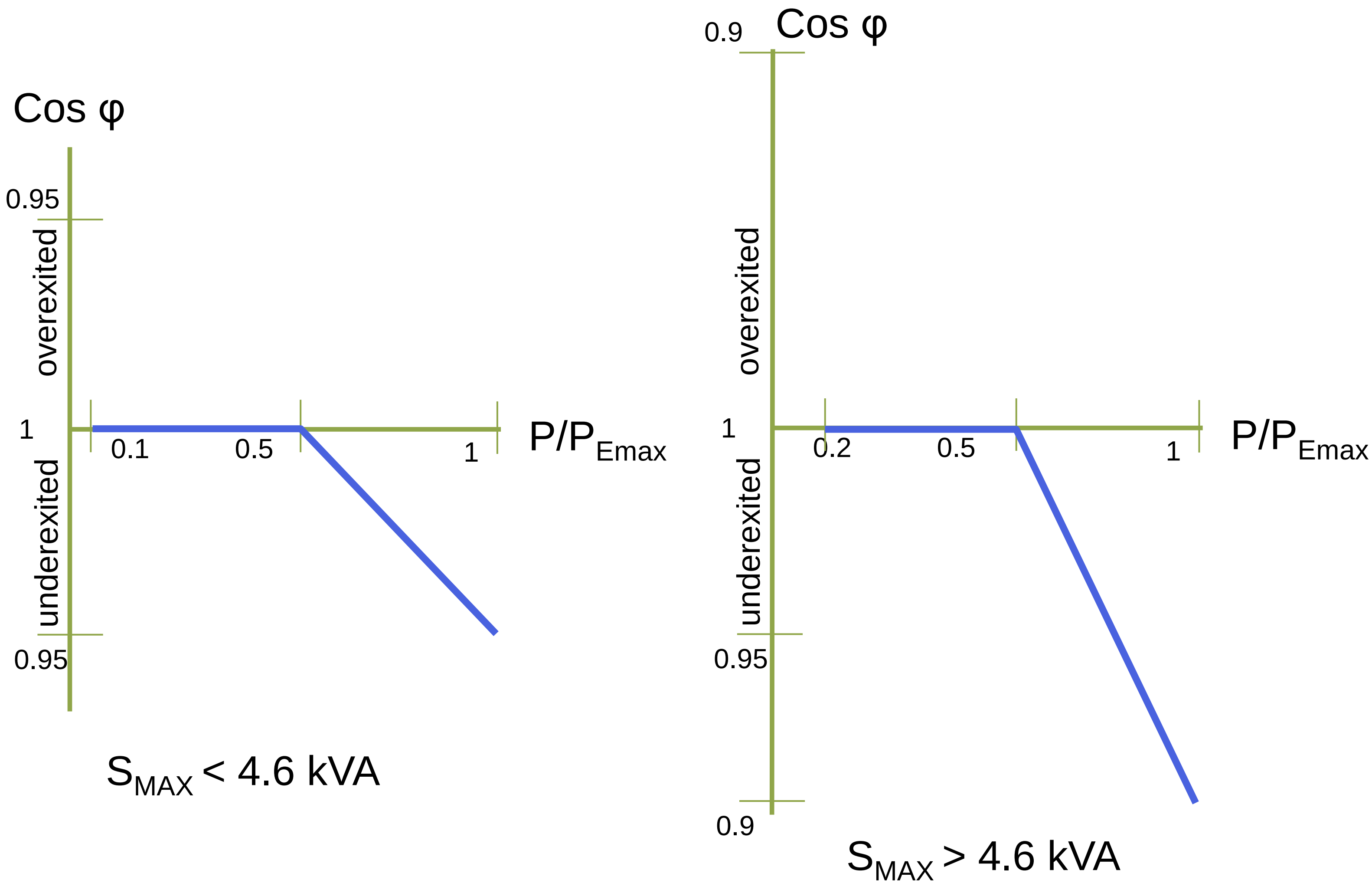


- Every PV plant has to fulfill the reactive power requirements. Reactive power can be provided via:
  - Q(P) active power
  - Q(V) grid connection point voltage
  - Constant cos φ

Source: E VDE-AR-N 4105:2017-07 (draft)

Source: E VDE-AR-N 4105:2017-07

Rooftop PV reactive power generation Q(P) in low voltage grid



Source: E VDE-AR-N 4105:2017-07

Exercise: Rooftop PV reactive power generation Q(P) in low voltage grid

- Assume a rooftop PV controls reactive power via Q(P) mode. The PV feeds in the maximum active power of 100 kW.
  Questions/tasks:
  1. At which cos phi shall the PV plant operate?
  2. Calculate the reactive power Q and the apparent power S?

P = 100 kW
Cos φ = ?
Q = ?
S = ?

$$S = \frac{P}{\text{Cos } \varphi}$$

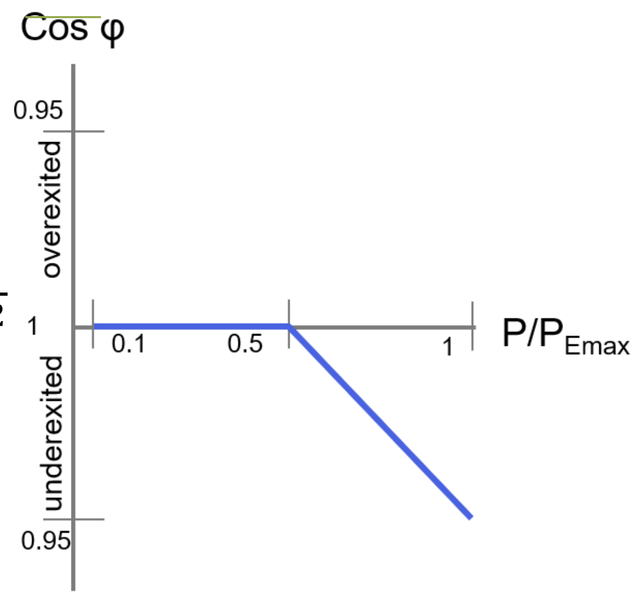
$$P = S \text{ x Cos } \varphi$$

$$Q = \sqrt{S^2 - P^2}$$

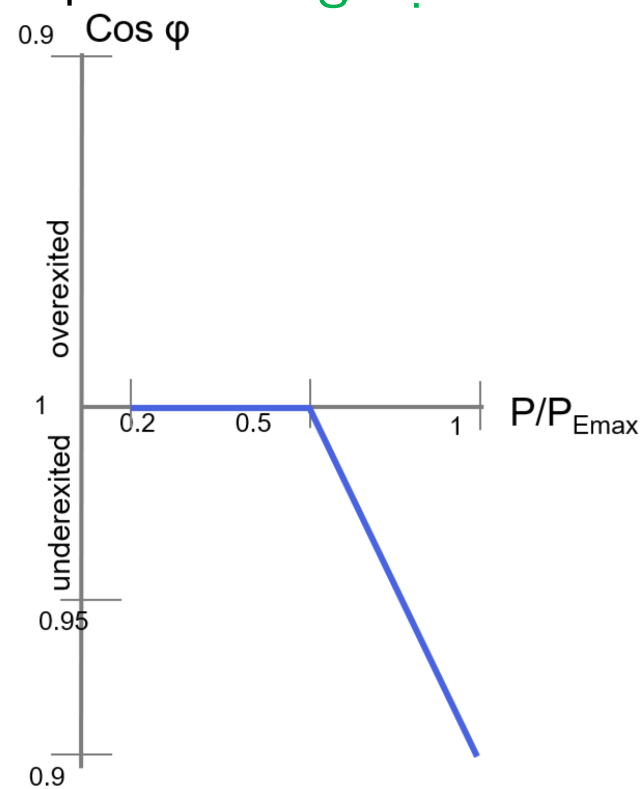
$$Q = \sqrt{S^2 - (S \ \text{Cos } \varphi)^2}$$

S = apparent power (VA)
P = active power (W)
Q = reactive power (VAR)
Cos φ = phase angle

Source: E VDE-AR-N 4105:2017-07

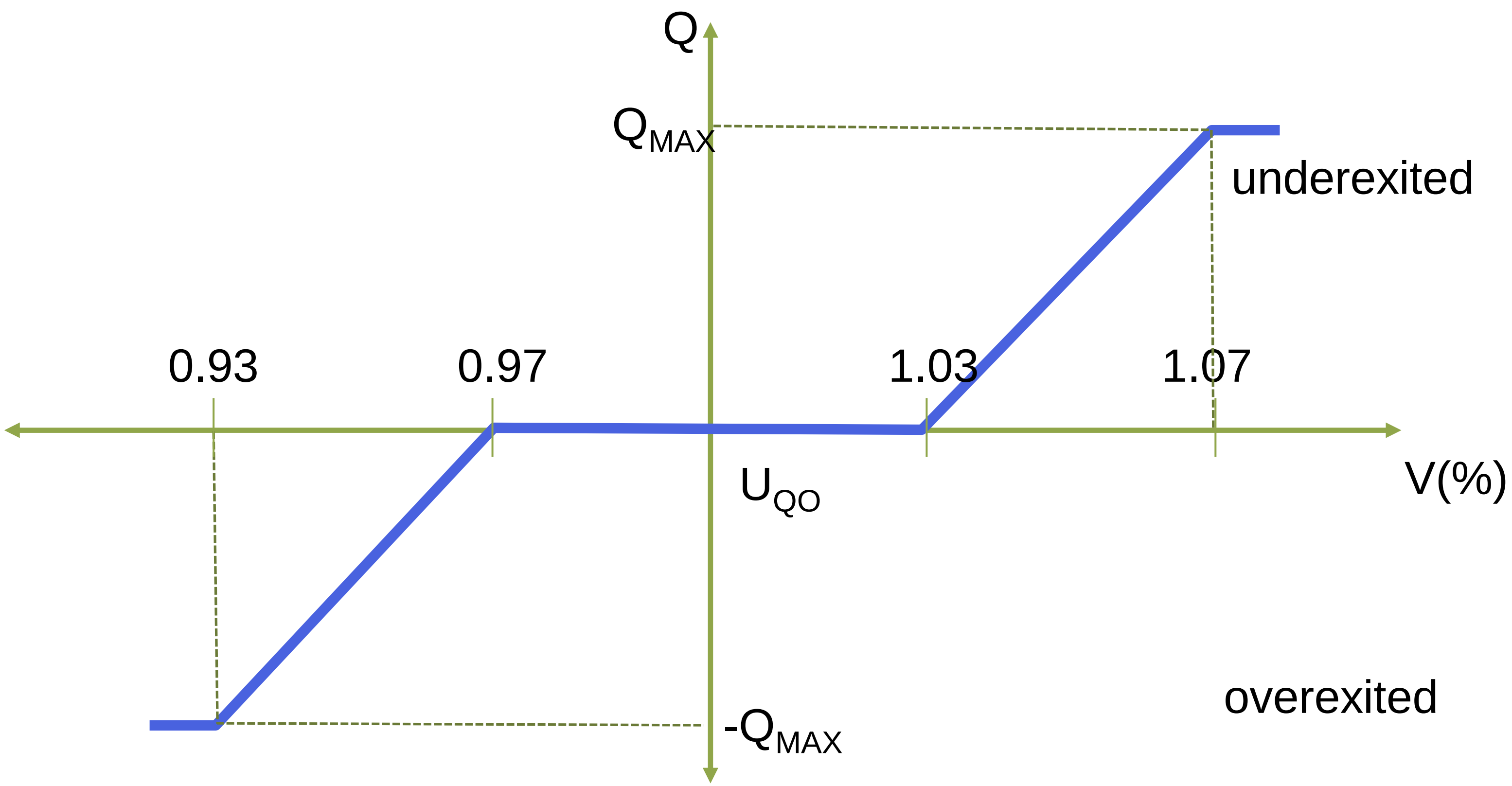


$S_{MAX} < 4.6$ kVA



$S_{MAX} > 4.6$ kVA

Rooftop PV reactive power generation Q(V) in low voltage grid



U_{QO} = reference voltage 230 V

Source: E VDE-AR-N 4105:2017-07 (draft)

Exercise: Rooftop PV reactive power generation Q(V) in low voltage grid

- Assume a rooftop PV with controls reactive power via Q(V) mode and the maximum cos φ is 0.9. The active power output is 200 kW and the voltage at the grid connection point is 7% smaller than the reference voltage. **Questions/tasks:**
  1. Shall it operate overexited or underexited?
  2. Calculate the reactive power Q.

P = 200 kW
Cos φ = 0.90
Q = ? kVAR
S = ? kVA

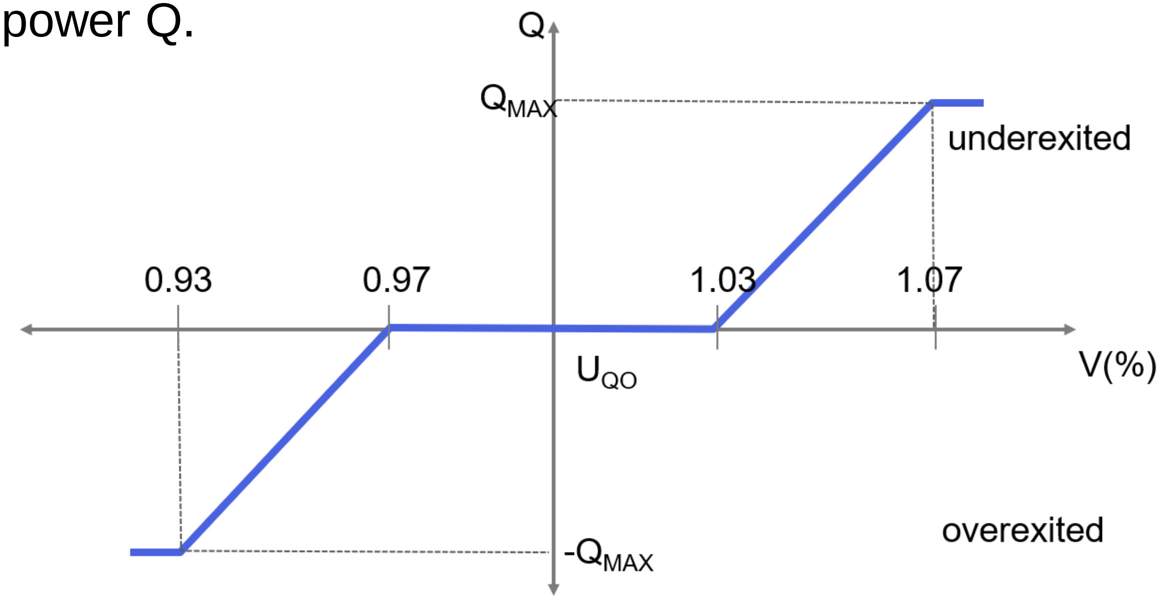
$$S = \frac{P}{\text{Cos } \varphi}$$

$$P = S \text{ x } \text{Cos } \varphi$$

$$Q = \sqrt{S^2 - P^2}$$

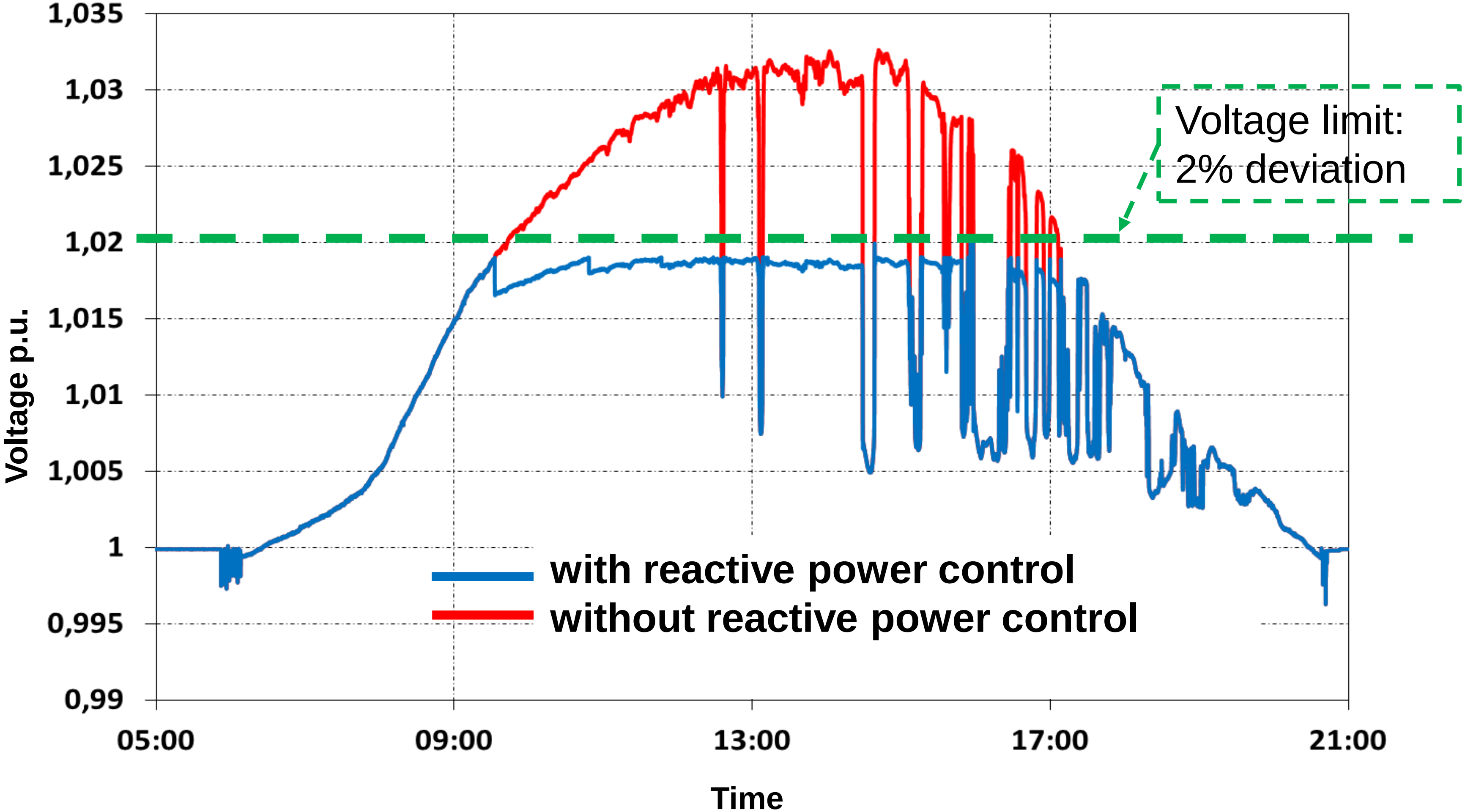
$$Q = \sqrt{S^2 - (S \text{ Cos } \varphi)^2}$$

S = apparent power (VA)
P = active power (W)
Q = reactive power (VAR)
Cos φ = phase angle



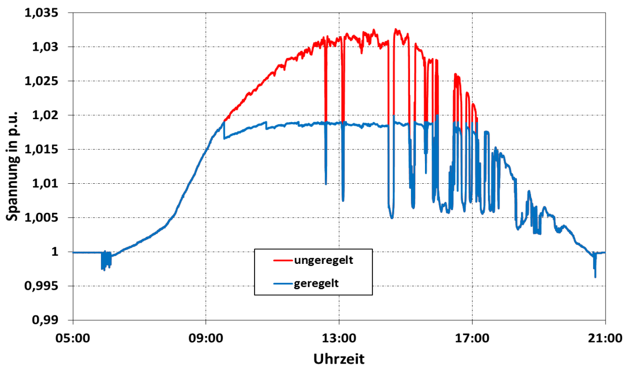
U_{QO} = reference voltage 230 V

Example: Voltage control with and without reactive power generation by a PV farm



Source: Energiequelle; Source: Prof. Dr. Ing. Rolf Witzmann, TU München,

Exercise: PV farm voltage analysis



- Analyse the previous chart together with your neighbour. Assume a 30 kV voltage grid (30 kV =1 p.u.)
- Questions:

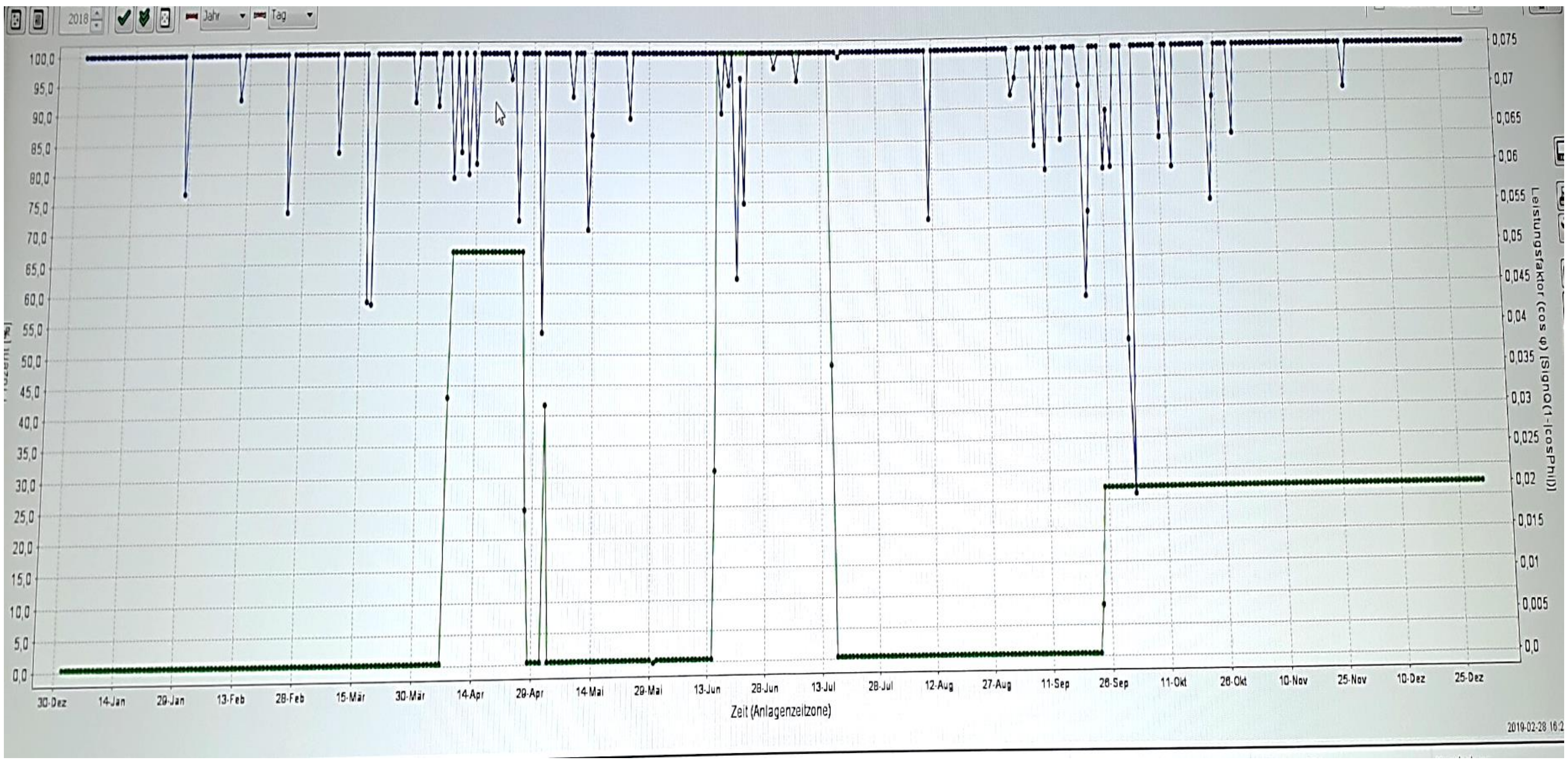
1. How high is the maximum voltage that the grid operator accepts at the grid connection point? ________
2. Which maximum voltage occurs at the grid connection point when the PV farm is in operation
   a. With PV inverter reactive power control __________
   b. Without PV inverter reactive power control __________
3. How low is the minimum voltage at the grid connection point? __________

Active power limitation and cos phi control of multi megawatt PV farm during one year

renac
renewables academy

- Active power limitation (blue, left scale)
- cos phi control (green, right scale)

Active power in % of installed capacity



Power factor, (1- cosine phi)

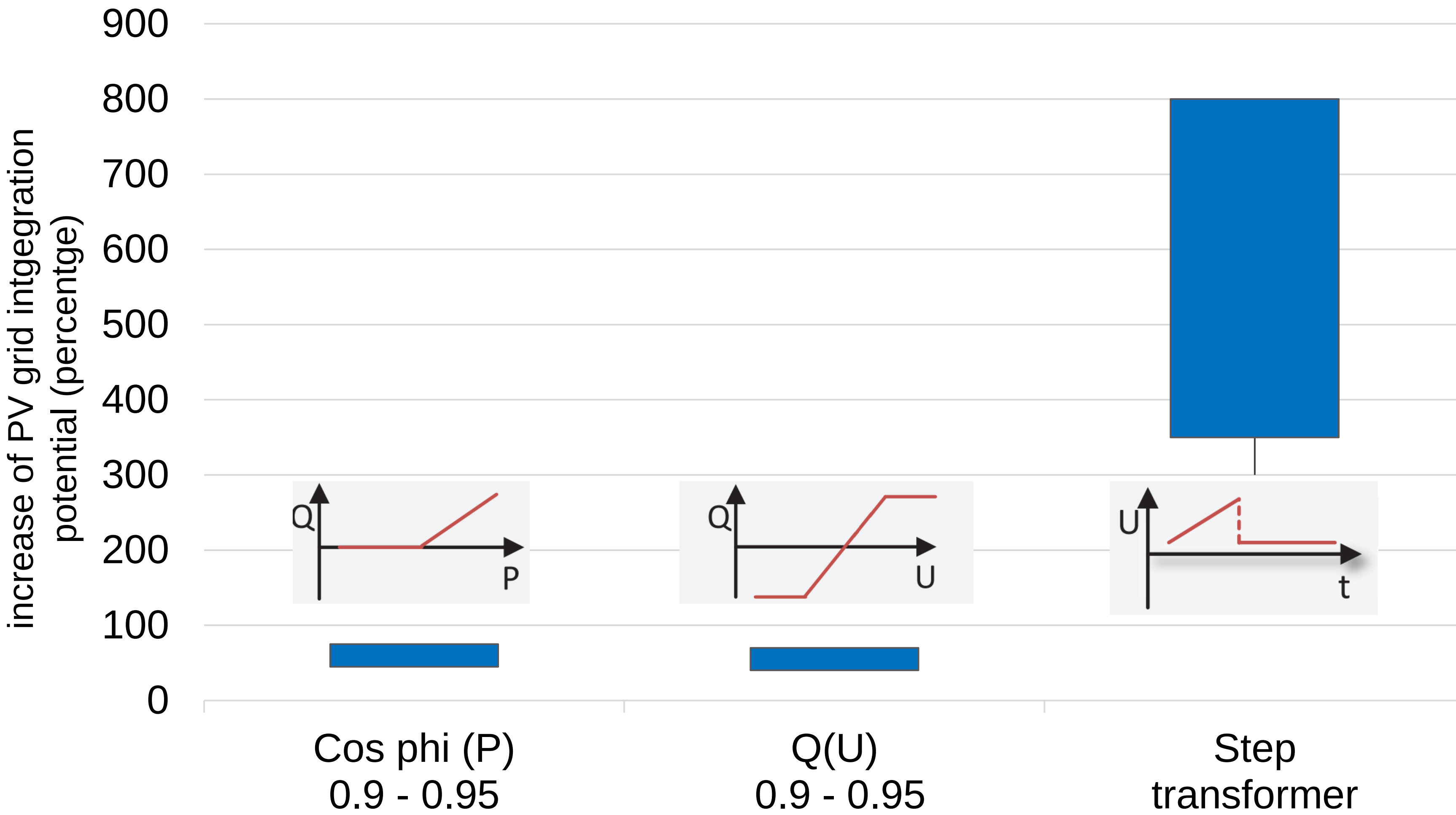
Foto: Tiedemann

Limits of voltage control with reactive power compensation

- Reactive power injection allows to control line voltage at the point of common coupling to some extent. The higher the voltage the more effective reactive power is because R/X ratio decreases with voltage.
- Reactive power injection allows stable network operation with high shares of renewables.
- Reactive power injection allows to install more distributed generation capacity without immediate network reinforcement or curtailment of peak generation.
- **But**, reactive power injection increases the current injected into the network. Increased currents create additional losses in the network: $P_{loss} = I^2 * R_{line}$.

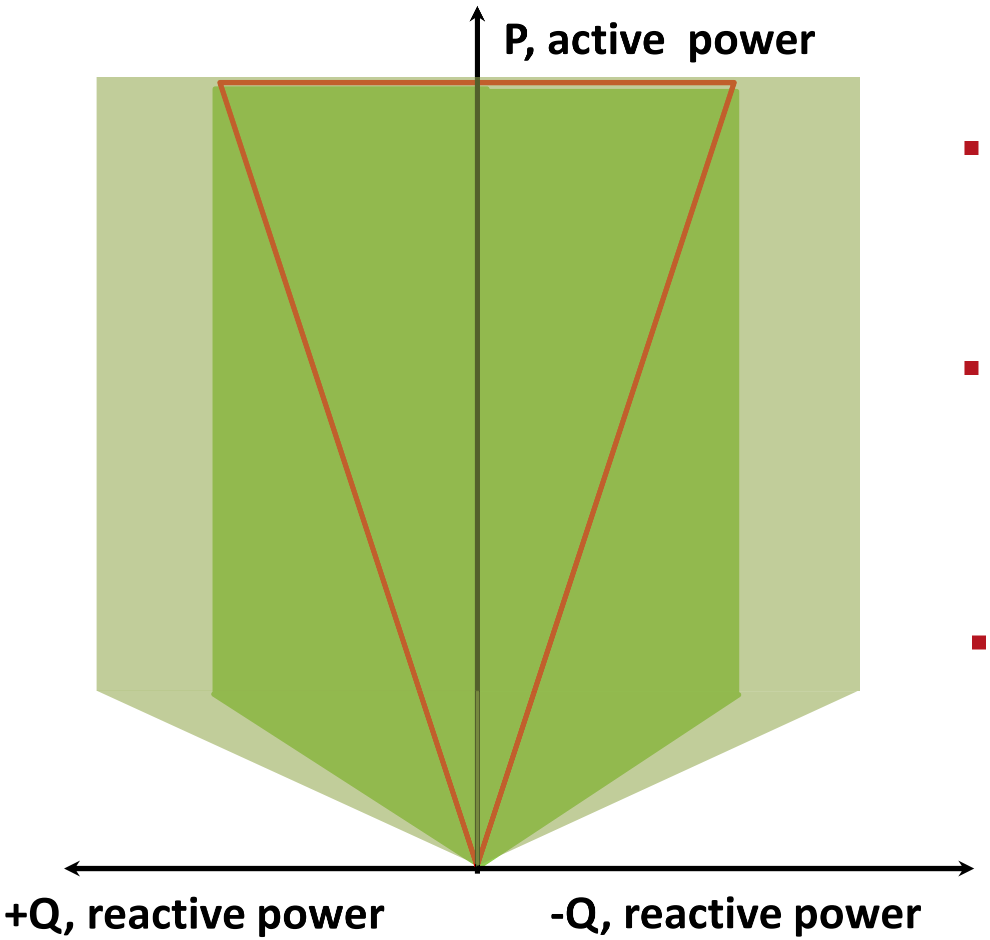
	Overhead line	Underground cable
Low voltage	R ≈ 0.3-0.5 Ω/km, R/X ≈ 2-3	R ≈ …0.1 Ω/km, R/X ≈ 5
Medium voltage	R ≈ 0.3-0.5 Ω/km, R/X ≈ 1-2	R ≈ 0.1… Ω/km, R/X ≈ 4
High voltage	R ≈ 0.2-0.3 Ω/km, R/X ≈ 0.1-0.3	R ≈ 0.1… Ω/km, R/X ≈ 0.1...
Extra High voltage	R ≈ 0.2-0.3 Ω/km, R/X ≈ 0.1	

Relative increase of PV grid intgegration potential of technical measures in low voltage distribution grids



Prof. Dr.-Ing. Bernd Engel, TU Braunschweig „Blindleistung zur Spannungsregelung im Niederspannungsnetz – PV-Anlagen und Elektromobilität U-Control-Technische und wirtschaftliche Untersuchung von Spannungshaltungskonzepten für Verteilnetze“, 29.01.2019 Blindleistungsseminar Berlin, Slide 5

Grid codes: different reactive power capability



- Characteristic with constant amount of reactive power (red)
- Standard characteristic for connection to the medium voltage grid, variable amount of reactive power (green)
- Standard characteristic for connection to high voltage grid with variable amount of reactive power (grey)

Source: Energiequelle

Grid code requirements overview

renac renewables academy

- **Active Power**
  - Maximum Active Power
  - Active Power Reduction due to setpoint change
  - Active Power Reduction in case of overfrequency
  - Active Power Gradient after restarting
- **Reactive Power**
  - PQ Characteristic
  - Reactive Power Change due to setpoint change
  - Reactive Power Step Function
  - Steady State Voltage Regulation - Q(U) Characteristic
- **Power Quality**
  - Voltage Changes due to switching operation
  - Flicker
  - Harmonics
- **Security Functions**
  - Disconnection from the power system due to overvoltage
  - Disconnection from the power system due to undervoltage
  - Disconnection from the power system due to overfrequency
  - Disconnection from the power system due to underfrequency
- **Cut-In Conditions**
  - Verification of Cut-In Condition in case of Frequency Deviation
  - Verification of Cut-In Condition in case of Voltage Deviation
- **Dynamic Behaviour**
  - Fault Ride-Through Testing Balanced & Unbalanced Faults
  - Dynamic Voltage Control

Source: Neumann

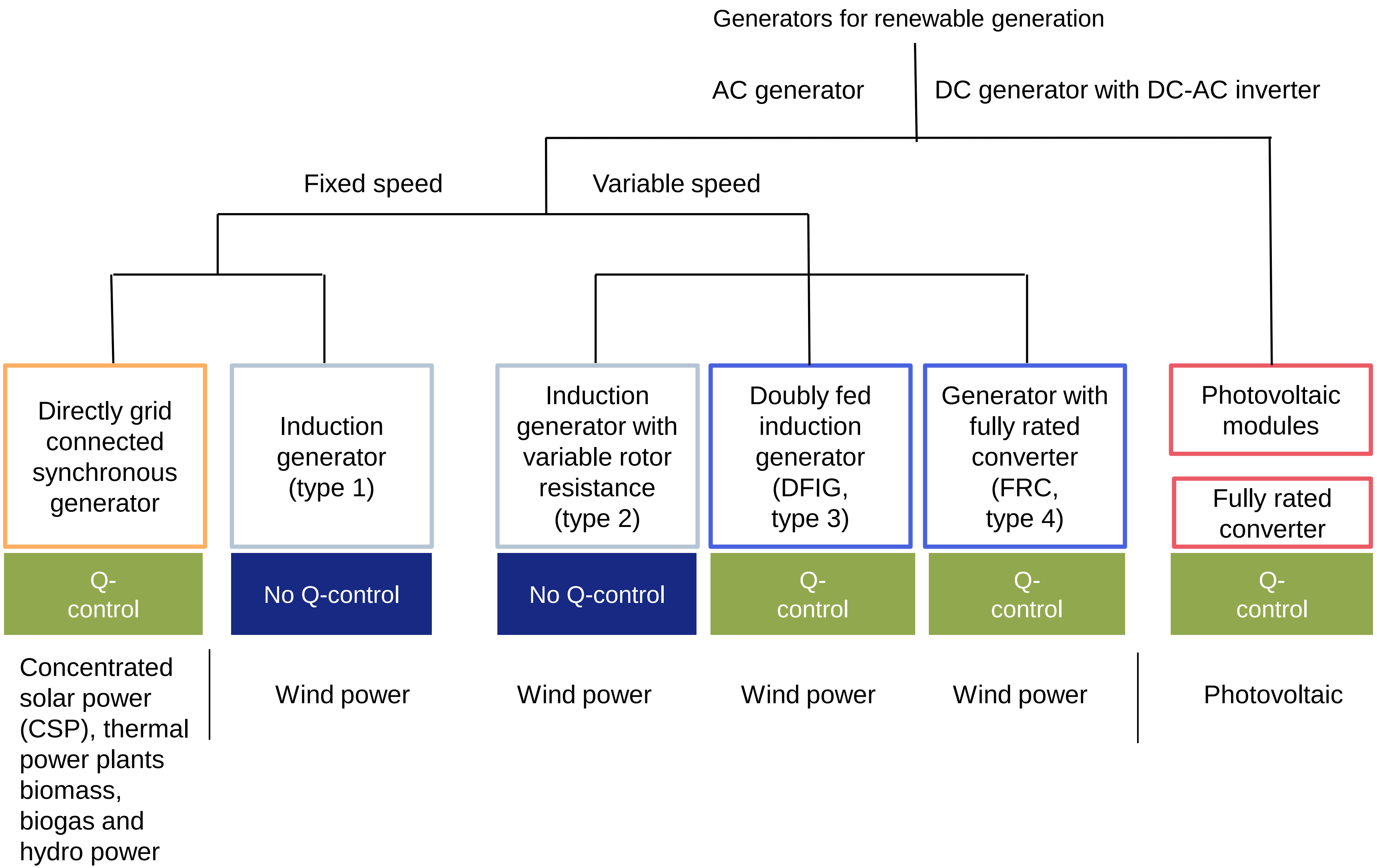
Generator concepts and voltage control - overview

Generators for renewable generation

AC generator

DC generator with DC-AC inverter

Generator concepts and voltage control - overview



Protection settings

Learning objectives

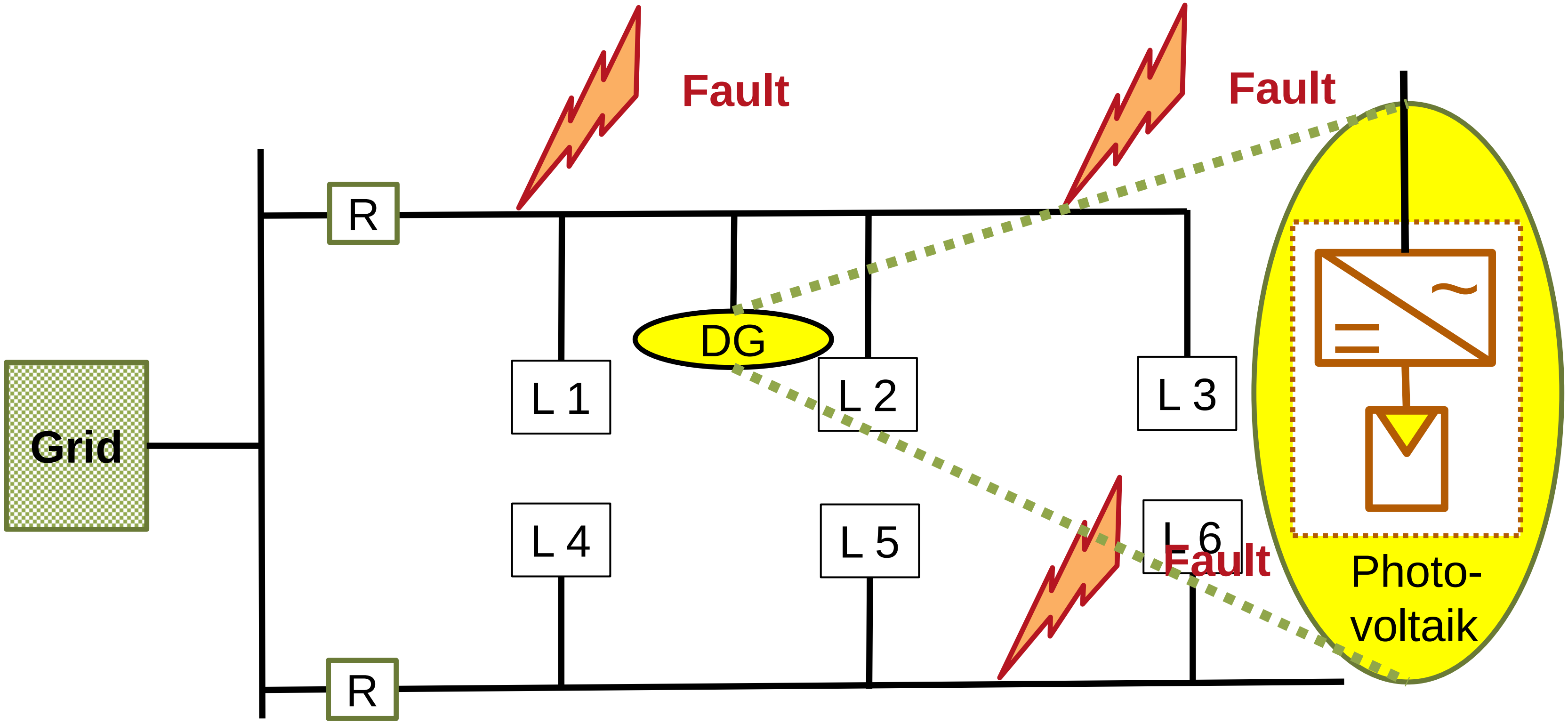
renac
renewables academy

After this lecture you will be able to:

- Explaing the role of possible PV roof top related changes to the protection settings of an existing power system as
  - blinding of protection
  - impact on distance protection
  - fault ride through
  - undesired islanding
  - false reclosing
  - false tripping
- Prepare for the future operation of electrical grids with higher levels of PV penetration

Learning objectives

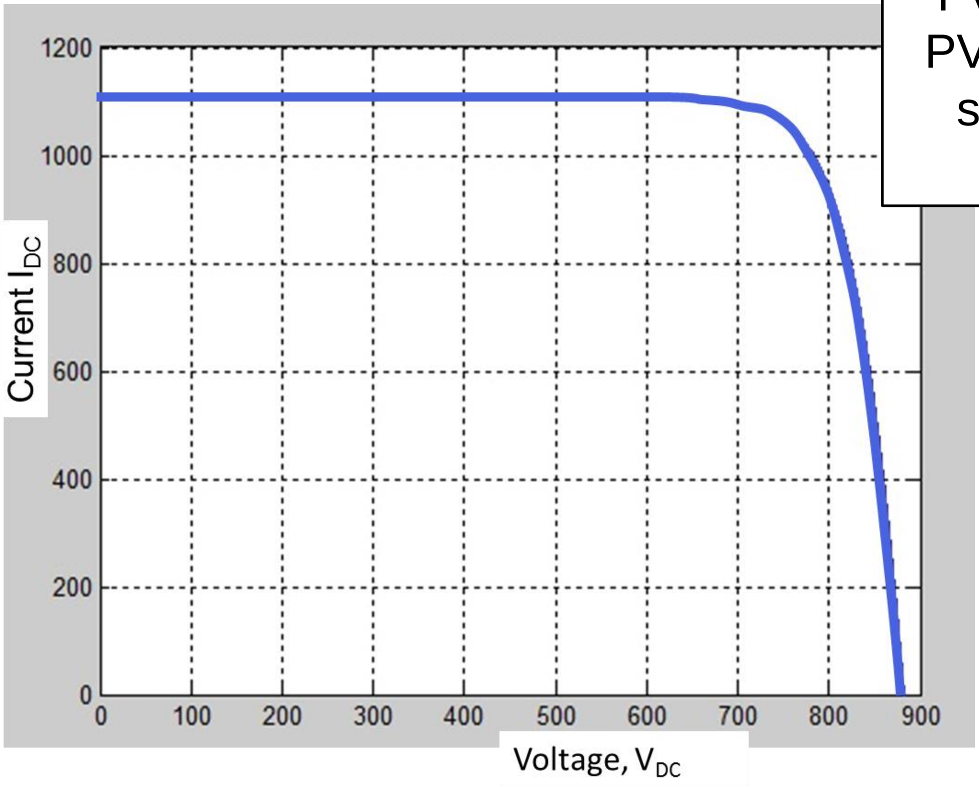
Three typical protection situations with distributed generation



R = Protection device with relay
DG = Distributed generation
L = Load
T = Transformer

Short circuit power provision

- Synchronous generator: 8 times nominal current
- Asynchronous generator: 6 times nominal current
- Inverter: 1 time nominal current

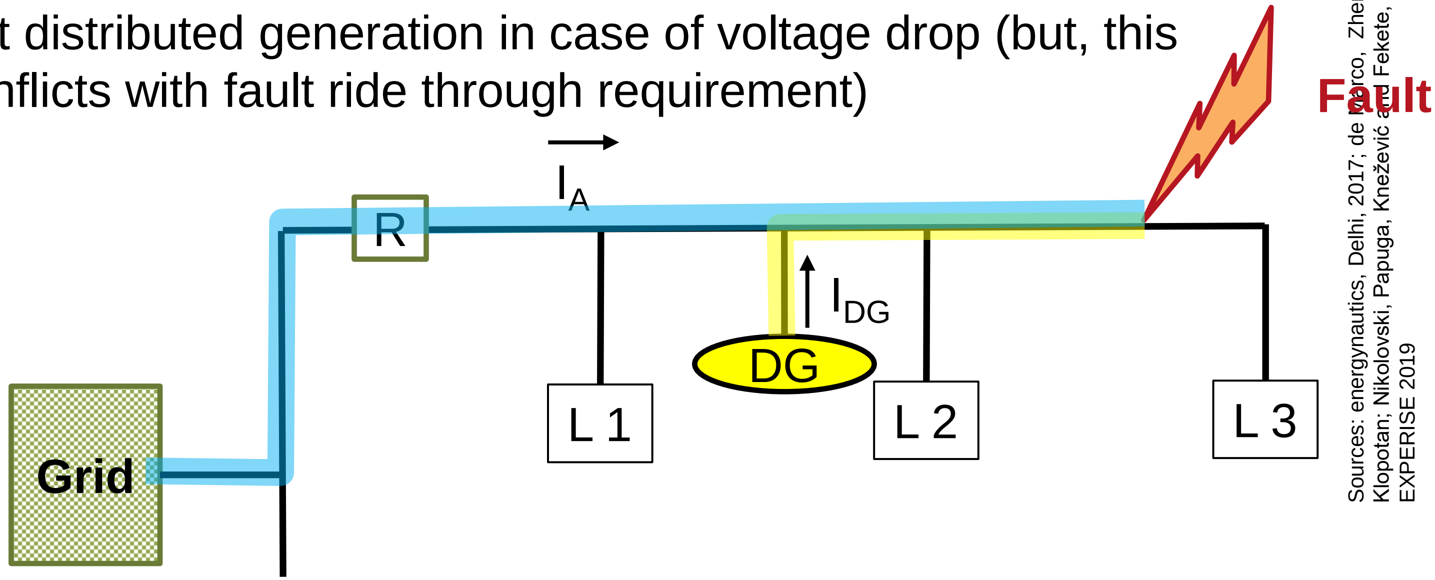


I-V curve of a PV array limits short circuit currents

Source: according to to low voltage regulation E VDE-AR-N 4105:2017-07 (draft) and RENAC-training material

Effect of distributed generation: Blinding of protection

- In case of a fault: Short circuit current is not only drawn from the transmission grid to trigger the protection devices. Short circuit current can also flow from distributed generation to the fault.
  → protection relay does not open the circuit because current set point might not be reached.
- Options for solutions:
  - Limit short circuit current of distributed generation or zero current mode
  - Disconnect distributed generation in case of voltage drop (but, this causes conflicts with fault ride through requirement)



Sources: energynautics, Delhi, 2017; de Marco, Zheng, Nikolovski, 2017; Gallery, Martinez and Klopotan; Nikolovski, Papuga, Knežević and Fekete, 2014; Gers and Holmes, 2011; Karsten Burges RE EXPERISE 2019

Impact on distance protection

$$V_A = I_A Z_A + (I_A + ID_G)\, Z_B$$

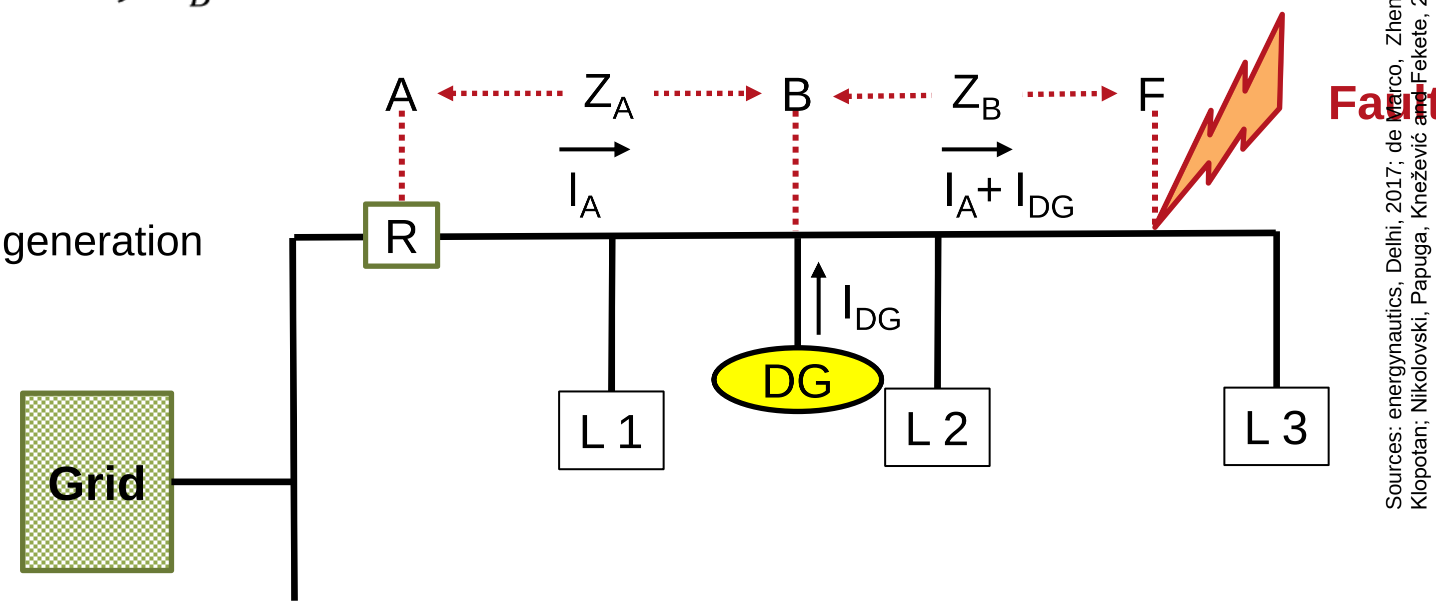
$$\frac{V_A}{I_A} = Z_A + \left(1 + \frac{I_{DG}}{I_A}\right) Z_B$$

$$with\ K = \left(\frac{I_{DG}}{I_A}\right)$$

$$Z_{Relay} = Z_A + (1 + K)\, Z_B$$

- In case of a fault behind “B” the impedance seen by the distance relay R is greater than that which actually occurs.
- Relay R sees an impedance Z_{Relay} that is equal to the relation of the current I_{DG} (total infeed by distributed generation) and the current I_A (current via the relay)
- → Sensitivity of relay is reduced

DG = distributed generation
I = Current
Z = Impedance
V = Voltage
R = Relay
L = Load
F = Fault

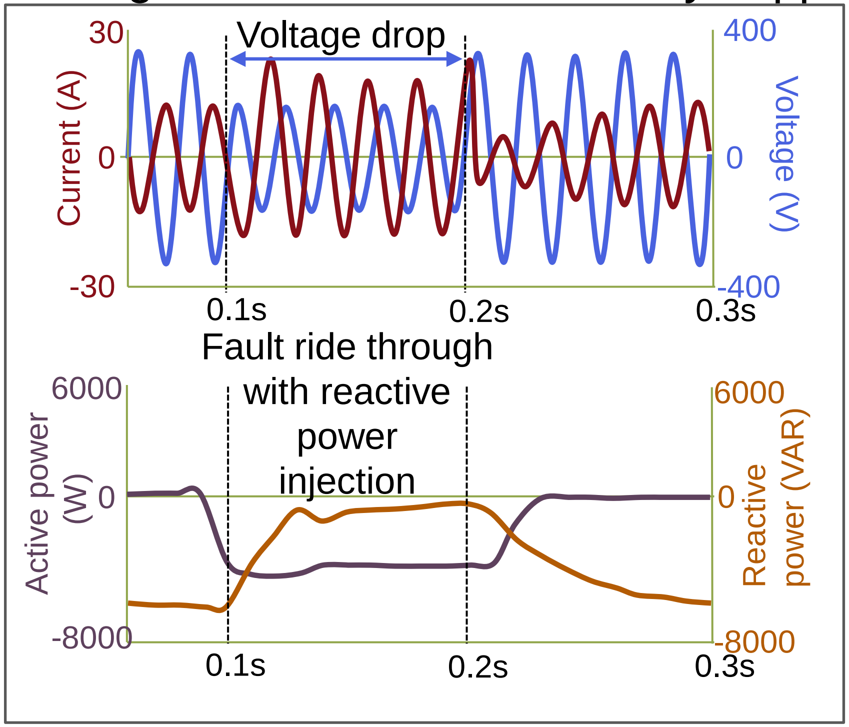


Sources: energynautics, Delhi, 2017; de Marco, Zheng, Nikolovski, 2017; Gallery, Martinez and Klopotan; Nikolovski, Papuga, Knežević and Fekete, 2014; Gers and Holmes, 2011 ;Karsten Burges RE EXPERISE 2019

Grid support with Fault Ride Through (FRT)

- Case A: Reactive current injection reduces the voltage drop in case of short circuits on transmission level → Inverters can support the grid by stabilising the voltage after a fault
- Case B: With FRT in its "zero current mode", PV inverters will curtail the current after a voltage drop, but they stay ready to resume generation immediately once voltage is restored, thus actively supporting the grid, even on LV level

Case A



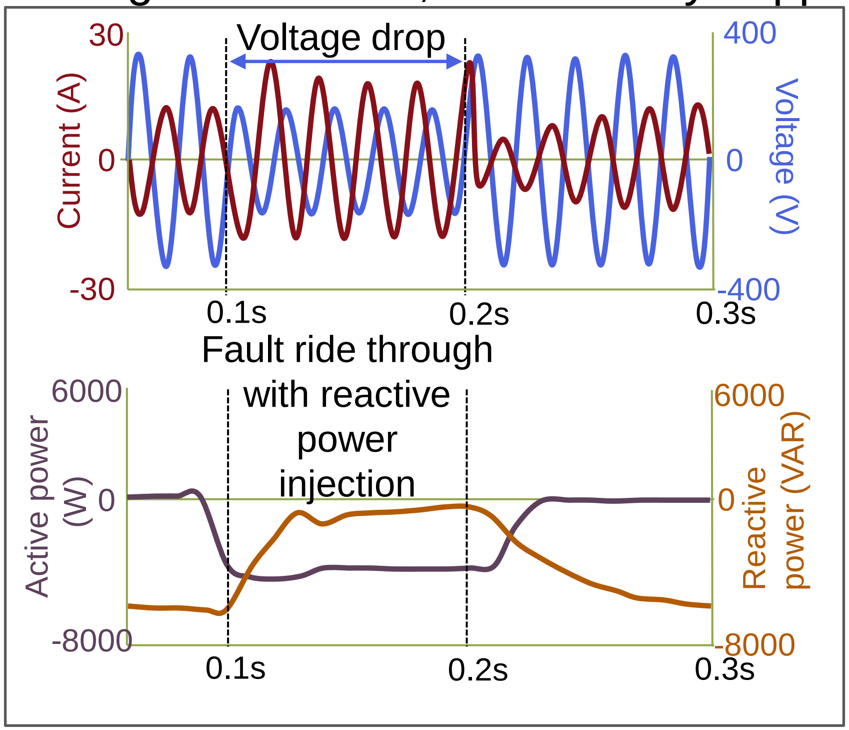
Case C: disconnection and very late synchronysation after fault clearance

source: energynautics, Delhi, 2017, adapted by RENAC

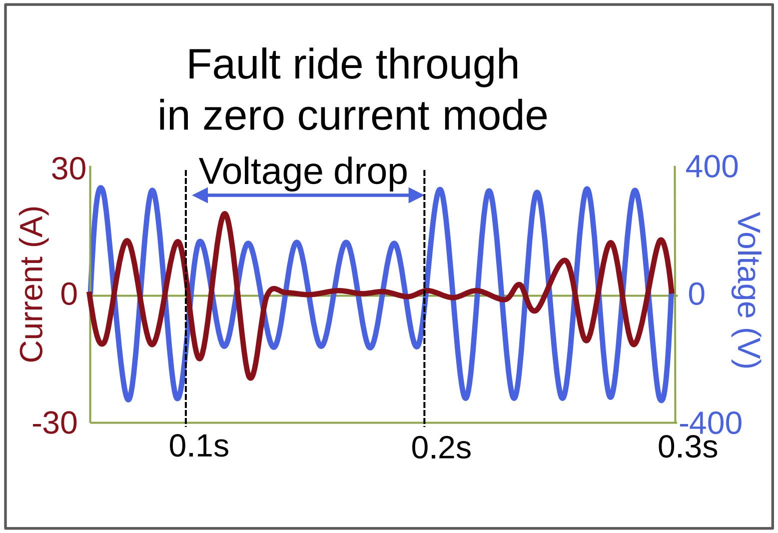
Grid support with Fault Ride Through (FRT)

- Case A: Reactive current injection reduces the voltage drop in case of short circuits on transmission level → Inverters can support the grid by stabilising the voltage after a fault
- Case B: With FRT in its “zero current mode”, PV inverters will curtail the current after a voltage drop, but they stay ready to resume generation immediately once voltage is restored, thus actively supporting the grid, even on LV level

Case A



Case B



source: energynautics, Delhi, 2017, adapted by RENAC

Case C: disconnection and very late synchronysation after fault clearance

Undesired islanding definition

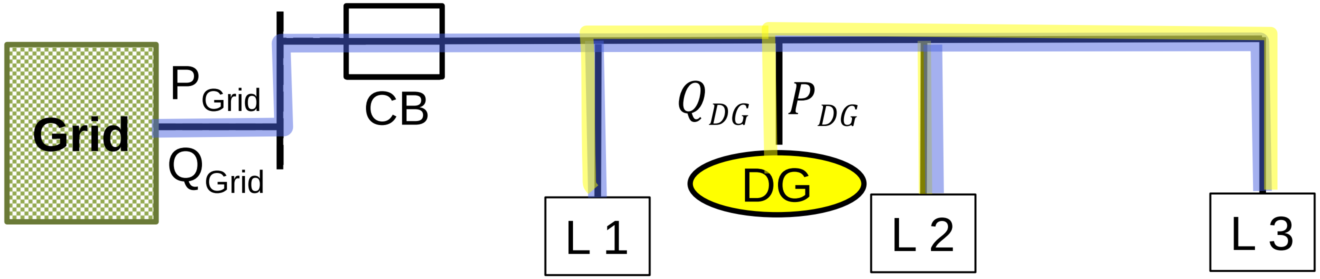
renac renewables academy

- Definition according to Electrical and Electronics Engineers (IEEE) Standard 1547:
  - A condition in which a portion of an Area Electric Power System (EPS) is energized solely by one or more Local EPSs through the associated point of common coupling (PCC) while that portion of the Area EPS is electrically separated from the rest of the Area EPS [5].
- Islanding is an undesirable operating condition because it causes risk
  - to the utility system (e.g. during maintenance)
  - safety of the utility customers, and
  - to the distributed generation (DG) itself.
- Anti-islanding is important if DG is large enough to allow a close balance between DG capacity and the local load

Source: "Robust hybrid anti-islanding method for inverter- based distributed generation" Maher. G. M. Abdolrasola

Undesired islanding

renac
renewables academy



- Normal operation: $P_{Grid} = P_{DG} - (P_{Load\,1} + P_{Load\,2} + P_{Load\,3})$
- In case the grid circuit braker opens (e.g. due to maintenance) power flow from the grid to the load is interrupted. The loads absorb the distributed generation power completely.
- Passive and active islanding detection measures exist

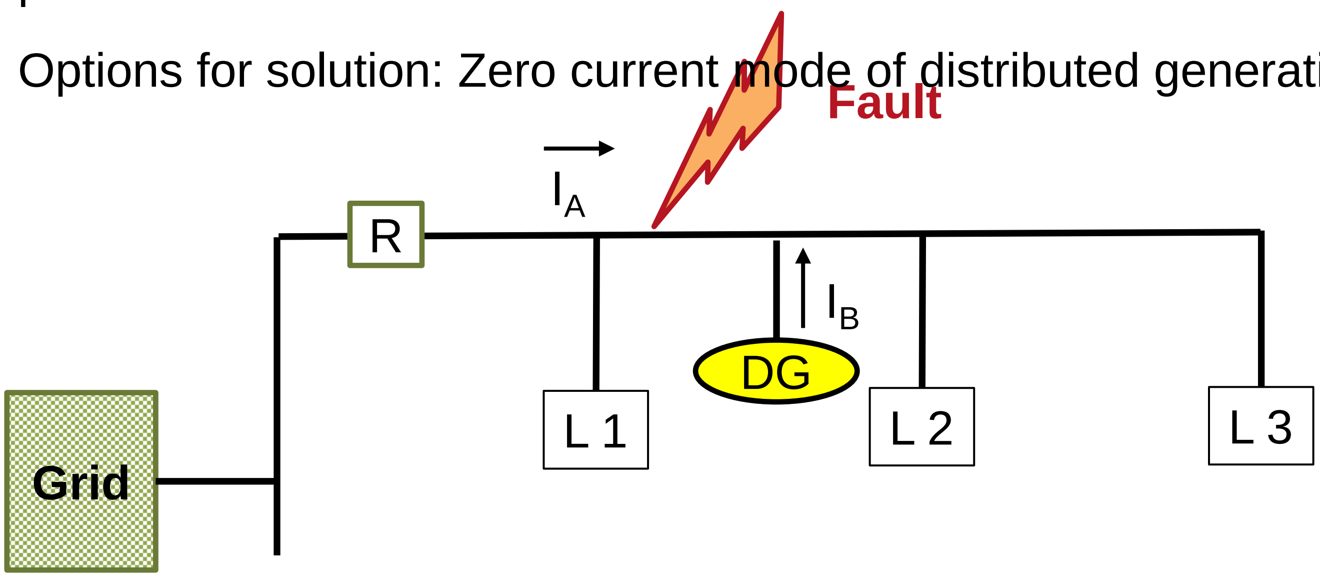
DG = Distributed generation
CB = Circuit braker
L = Load

P = Active power
Q = Reactive power

Sources: energynautics, Delhi, 2017; de Marco, Zheng, Nikolovski, 2017; Gallery, Martinez and Klopotan; Nikolovski, Papuga, Knežević and Fekete, 2014; Gers and Holmes, 2011;Karsten Burges RE EXPERISE 2019

False reclosing

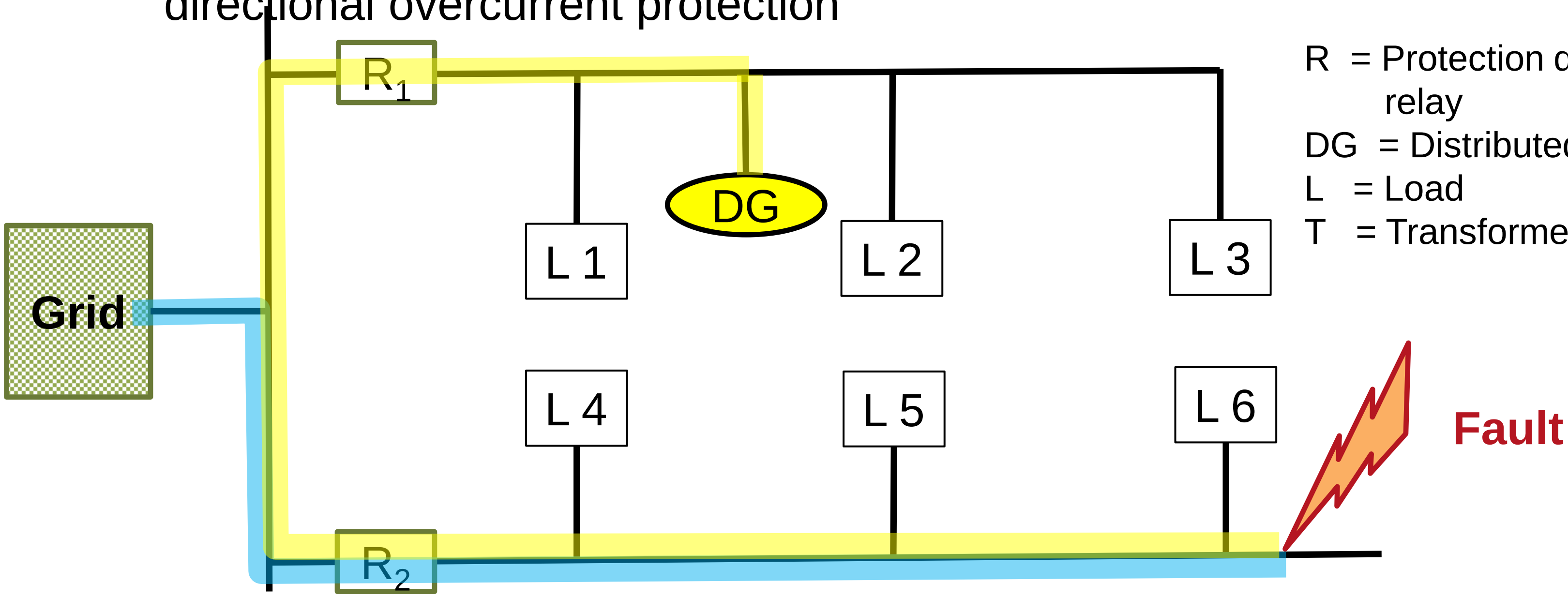
- The purpose of reclosers R is to detect a fault. It opens the circuit to stop an arc and can close automatically to minimise supply interruptions.
- If distributed generation continues to feed in during the reclosing sequence the arc might continue. The fault could seem permanent.
- Options for solution: Zero current mode of distributed generation



Sources: energynautics, Delhi, 2017; de Marco, Zheng, Nikolovski, 2017; Gallery, Martinez and Klopotan; Nikolovski, Papuga, Knežević and Fekete, 2014; Gers and Holmes, 2011;Karsten Burges RE EXPERISE 2019

False tripping

- Adjacent feeder might contribute to short circuit provision and short circuit current might exceed settings of relay of healthy feeder
- Healthy feeder relay R_1 might trip before the fault is cleared by relay R_2 of the disturbed feeder
- Options: adapt fault clearing time of relays or directional overcurrent protection



R = Protection device with relay
DG = Distributed generation
L = Load
T = Transformer

Sources: energynautics, Delhi, 2017; de Marco, Zheng, Nikolovski, 2017; Gallery, Martinez and Klopotan; Nikolovski, Papuga, Knežević and Fekete, 2014; Gers and Holmes, 2011;Karsten Burges RE EXPERISE 2019

Thank you!

Albrecht Tiedemann

Renewables Academy (RENAC)

Schönhauser Allee 10-11
D-10119 Berlin
Tel: +49 30 58 708 70 40
Fax: +49 30 58 708 70 88
tiedemann@renac.de

renac
renewables academy

www.renac.de